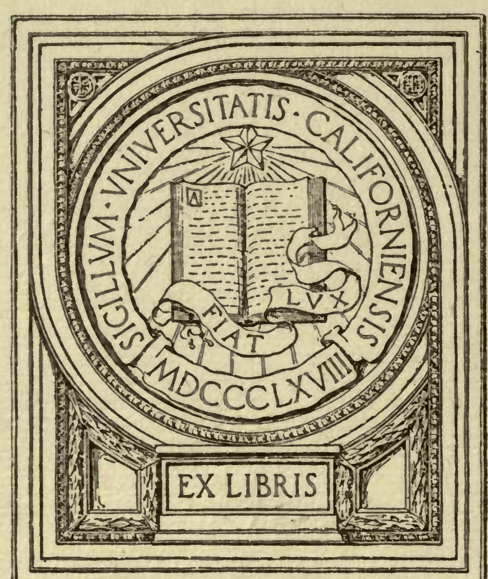

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UNIVERSITY OF MISSOURI
COLLEGE OF AGRICULTURE
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RESEARCH BULLETIN NO. 21

An Experimental Study of the Rest Period in Plants

Physiological Changes Accompanying Breaking of the Rest Period

FIFTH REPORT

COLUMBIA, MISSOURI
June, 1915

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An Experimental Study of the Rest Period in Plants

Physiological Changes Accompanying Breaking of the Rest Period

FIFTH REPORT

W. L. HOWARD

INTRODUCTION

The object of the physiological investigations described in this bulletin was to secure information on the complex problem of the specific effects produced by anesthetics and other agents employed in breaking the rest period of woody plants.

The existence of a rest period in plants has been thoroughly demonstrated by a number of investigators. At the Missouri Agricultural Experiment Station[1] approximately 300 species of woody plants have been studied and practically all were found to have a rest period of varying duration and intensity.

Approximately 100 species of herbaceous perennial plants were studied, and, while the number that could be said to have a rest period was not determined, it was thought that from 10 to 25 per cent possessed a resting phase. Numerous experiments with many of our common species of bulbs indicated that all of them are possessed of a pronounced rest period. Investigations covering about 200 species of seeds of woody and herbaceous plants yielded the information that from 50 to 90 per cent passed through a resting phase some time after ripening.

The rest period in woody plants is not all the same or even analogous to the winter dormant period. In woody plants, such as peach and apple trees, the rest period has been observed to set in as early as May in the peach, and in early June in the apple. These, however, were extreme cases as the trees had been greatly weakened from various causes which resulted in an early cessation of growth. The rest period probably begins in a given twig shortly after the formation of its terminal bud. It has been observed that apple trees of normal vigor form a large number of terminal buds the latter part of June or early in July under Missouri conditions. Under similar conditions, a peach tree would continue growth until later in the season.

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[1] Howard, W. L., Experimental Study of the Rest Period in Plants. Mo. Agr. Exp. Sta. Research Bulletin 1.

————————, Rest Period Studies with Bulbs and Herbaceous Perennial Plants. Mo. Agr. Exp. Sta. Research Bul. No. 15.

————————, Rest Period Studies with Pot-grown Woody Plants. Mo. Agr. Exp. Sta. Research Bul. No. 16.

————————, An Investigation of the Rest Period of Seeds. Mo. Agr. Exp. Sta. Research Bul. No. 17.

Not all the twigs of a tree begin their period of rest at the same time. It is probably safe to say that deciduous trees and shrubs usually begin to enter their rest period in July, and thruout August and September become gradually more and more dormant until complete defoliation occurs and all ordinary vegetative processes cease.

Herbaceous perennial plants have not been carefully studied with regard to the exact time of entering the rest period. However, it has been observed that several species at least cease growing in late July or early August. The cessation of growth is marked by the formation of strong buds on the crown of the root stock. Many plants of this kind continue growing until the approach of cold weather, when vegetative activity ceases as indicated by the formation of resting buds. While the rest period of woody plants continues into the winter, and may even last until spring in some species, it probably does not persist so late in herbaceous forms. Some of these seem capable of growing shortly after they become dormant in fall, while practically all that have been experimented with seem able to begin growing without treatment after a dormant period of two months or less. It may, therefore, be said that the rest period in woody plants in most cases lasts from two to four months; in herbaceous species it probably will not last on the average more than two to six weeks.

Bulbs begin their rest within two to four weeks after flowering. As soon as the leaves of such plants have died, the bulbs may be said to be in the misdt of their period of rest. The rest period of bulbs commonly lasts from June until late fall or early winter, or in other words, from one to six months as regards root growth, and five months longer if the time that actually elapses before leaves or flowers appear above ground under natural conditions is considered. Practically all bulbs resume top growth in December, if supplied with heat and moisture. The same is true of some species of woody plants and a great many herbaceous forms. The rest period of a seed may begin at maturity, or during the curing process which lasts from one to four weeks after harvesting. The length of the rest period in seeds varies as greatly as it does in woody and herbaceous plants. In fact the rest period of seeds in herbaceous and woody species is very similar to that of the parent plant.

The cause of the rest period is not definitely known. It has been attributed to both inner causes and environmental conditions. However, the experimental evidence presented in this bulletin strongly indicates that all the phenomena connected with the entire resting phase, are closely associated with the work of enzymes. The beginning of the rest, particularly in woody plants, appears to be wholly due to inner causes, but before the complete state of rest is reached, outer conditions may help to hasten the approach of the period of dormancy. In like manner the ending of the rest may take place from inner causes but may be either hastened or delayed by the environmental conditions under which the plant is growing. For the most part, tho, it may be said that the rest sets in and later passes away, independent of outward conditions.

Why the length of the rest period varies so greatly among the different species is not known. Apparently tho, this is due to hereditary causes as all the manifestations of the rest, so far as we are informed, are fairly constant for each species. This is particularly true of woody forms. Even with a constant supply of warmth and moisture many woody plants of the temperate zone pass into a state of rest and shed their leaves. There are no data showing that investigators have tried to prevent the rest of such plants from setting in. Herbaceous forms behave differently. Klebs[1] by certain cultural methods, actually prevented the rest period, or at least the winter rest, from beginning with certain herbaceous plants, thus causing them to make an uninterrupted growth thruout the year.

For the purposes of the present discussion, the rest period may be defined as a phase or stage in which plants are, for the most part, incapable of responding to favorable growing conditions.

It has been thoroly proven that by means of various treatments, the rest period of plants, as well as seeds, can be broken and the plants and seeds revived, thus causing them to begin growing within a few days or a few weeks. Various rest breaking agents, such as ether, frost and desiccation have been employed. Many other materials have been used with success by various investigators.

Johannsen[1] succeeded in breaking the rest period of many plants by exposing them to ether or chloroform vapors. Molisch[2] origin-

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1. Klebs, G., Willkürliche Entwickelungsänderungen bei Pflanzen. pp. 129-138, 1903.

1. Johannsen, W., Das Aetherverfahren beim Frühtereiben mit Besonderer Berucksichtigung der Fliedertrieberei, 1906.

2. Molisch, H., Forcing Plants by Warm Baths. Sci. Amer. Sup. 66 (1908) Exp. Sta. Rec. 20, p. 640.

————————, Radium as a Means of Forcing Plants. Exp. Sta. Rec. 27, p. 437.

ated the so-called "warm water bath" as a forcing agent and found radium emanations to be effective for breaking the rest period. Jesenko[1] caused earlier growth in woody twigs by immersing them in weak alcohol. He obtained similar results by treatments with weak solutions of hydrochloric and tartaric acids. Weber[2] demonstrated that mechanical injury induces resting buds to begin growth. Lakon[3] claimed to have secured earlier bud development by using nutrient salt solutions. Ethyl bromide and other vapors were used by McCallum.[4] Harshberger[5] found that resting buds which were treated with NH_4OH grew before untreated buds. Bos[6] used the galvanic current as a means of arousing plants from their dormancy. Placing plants in a vacuum, according to Stuart[7] was an effective means of breaking the rest period. Bathing the twigs in plant extracts, $CuSO_4$, KCl, $NaNO_3$, oxalic and acetic acid dilutions have induced somewhat earlier growth of buds. Similar results were obtained by painting the twigs with MnO_2. (See page 45).

The value of agents and methods for breaking the rest period varies with the species and other factors, such as time and intensity of application, condition of the twig, etc. Some agents are more effective than others. In general, the intensity of all treatments, that is, the concentration of the liquids, the density of the vapors, the duration of application or the degree of heat, etc., must be decreased as the season advances and as the close of the rest period is approached. Applications which are very effective in December may be very injurious during March.

RESUME OF THEORIES REGARDING THE INFLUENCE OF REST PERIOD BREAKING AGENTS

The miscellaneous materials that have been successfully used in breaking the rest period have given rise to much speculation as to their specific effect. It is, indeed, striking to find that the phenomenon of growth is started by such different agencies as heat, cold, increased and decreased water content, anesthetics, narcotics, gases and liquids, bases and acids, salts singly or combined, electricity, mechanical injury, and in vacuo. In other words, while the different agencies mentioned may not all have the same specific effect on the plant, they all produce the same ultimate results, that is, tend to shorten the normal rest period of plants.

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[1] Jesenko, Fr., Einige neue Verfahren die Ruheperiode der Holzgewächse abzukurzen. Ber. d. d. Bot. Ges. (1911) 29, p. 273.

[2] Weber, F., Untersuchungen Ueber die Wandlungen des Stärke und Fettegehaltes der Pflanzen insbesondere der Bäume. Bot. Centrlb. 113 (1910) p. 166.

[3] Lakon, G., Influence of Nutrient Solutions on the Winter Rest of Woody Plants. Ztsch. f. Bot. 4, pp. 561-83.

[4] McCallum, W. B., On Forcing Plants. Arizona Sta. Report, 1909, pp. 584-86.

[5] Harshberger, J. W., Action of Chemical Solutions on Bud Development: An Experimental Study of Acclimatization. Proc. Acad. Sc. Phil. 61, pp. 57-110.

[6] Bos, H., Wirkung galvanischer Ströme auf Pflanzen in der Ruhperiode. Biolog. Zentrabl. (1907) 27, No. 2.

[7] Stuart, W., The Role of Anesthetics and other Agents in Plant Forcing. Vermont Sta. Bul. 150, pp. 451-480; also Trans. Mass. Hort. Soc. 1909, pp. 67-87.

But how do all these various agencies affect the physiological processes of the resting tissue? Do all have a similar influence, or do some bring about growth in one way, for example, by desiccation, and some in another, as for example, by increasing respiration? These were some of the main questions to be answered by the investigations reported in this bulletin.

Not very much experimental data have been contributed toward explaining the specific influence exerted by the various agencies used for breaking the rest period in plants. However, considerable has been written regarding the probable action of rest period breaking agents. Claude Bernard[1] thought that etherization caused a coagulation of the protoplasm. Raphael Dubois[2] found marked dehydration taking place in plant tissues which were etherized. Johannsen[3] pointed out that dehydration occurs only after the ether has severely injured the tissue. Nevertheless, Dubois' experiments seem to have influenced later authors to adopt the theory that ether and chloroform have the same influence on plants as drying and freezing—viz., that they cause a desiccation of the living tissue. Aymard[4] supports this view very vigorously. Stuart[5] seems to favor this hypothesis. Regarding anesthetics he says: "Their effect upon the plant is to arrest growth, extract moisture from the cell protoplasm, and thru these physiological derangements, impart a severe shock to the whole plant which when removed causes a decided growth reaction." Similarly, he believed that toxic substances (acetone, alcohol, etc.) and non-toxic agents (freezing, vacuum treatment, desiccation) "arrest growth and remove moisture from the plant tissue much in the same manner as anesthetics." It is quite apparent that warm water baths which are very useful in shortening the rest do not bring about a drying effect. In this case Stuart believes that "hot water imparts a distinct shock to the cell protoplasm and tissue and acts as a solvent in softening up the winter protecting scales inclosing the leaf and flower buds."

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[1] Bernard, Claude, See reference to Johannsen, p. 65.

[2] Dubois, Raphael, See reference to Johannsen, p. 65.

[3] Johannsen, W., Das Aetherverfahren beim Frühtreiben, etc. Zweite Anfl. 1906.

[4] Aymard, J., See Howard Mo. Exp. Sta. Research Bul. No. 1, p. 24.

[5] Stuart, W., The Role of Anesthetics and Other Agents in Plant Forcing. Vt. Sta. Bul. 150, pp. 451-480.

Johannsen[1] and Overton[2] showed clearly that desiccation cannot be caused by the mild doses of ether which are effective in breaking the rest period. Additional experimental evidence in support of this fact is given on page 37 of this bulletin. Johannsen[3] believed that etherization might either affect the vegetative activity, or it might unfavorably influence the obstacles or inhibiting factors of growth. He explained that small amounts of ether were apt to favor vegetative activity, while larger doses, such as are given when the rest period is to be broken, weaken or devitalize those factors which are inhibiting growth, thereby indirectly favoring growth.

According to Drude, Nauman and Ledien[4] ether and chloroform affect plants by checking some of the changes within the plant cell, while at the same time increasing respiration. Muller-Thurgau[5] demonstrated that potatoes kept at a low temperature become richer in sugar. Beltz[6] is of the opinion that ether and chloroform bring about an enlargement of the cell similar to that occurring in springtime. Molisch[7] pointed out that the warm bath method of treatment affects plants by reason of the high temperature, the inhibition of respiration under water, prolonged contact with water and inbibition of water into the plant, thus facilitating the diosmosis of substances in the cells and tissues. Iraklionow[8] believed that thru the influence of the warm water bath the resting mechanism of growth is set in motion thru the removal of a "catch." As a result of this release, proferments are brought into an active condition. These liberated enzymes then function as a lubricant which hastens the reactions necessary for life. Kleb[9] held that during the rest period there is an accumulation of organic foods which have been assimilated after length growth has been suspended, but while the leaves are still active. He says: "From this viewpoint we can argue that every rest period can be broken since it depends upon regeneration of fermentative activity." He pointed out that a combination of high temperature and humidity favor fermentation; and he thought it probable that the influences of ether could be traced to this factor. He, however, made no direct experiments to prove his statements.

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[1] Johannsen, W., Das Aethervergfahren beim Frühtreiben, etc.

[2] Overton, See reference to Johannsen, p. 58.

[3] Johannsen, W., Das Aetherverfahren, etc. p. 49.

[4] Drude, O., Nauman, A., and Ledien, F., Gartenbau Versuche in Dresden 1902-03. Jahresber. VII der "Flora" zu Dresden.

[5] Müller-Thurgau, JH. Landw. Jahresberich. Bd. 14.

[6] Beltz, W. J. The Effects of Etherization on Plants. Exp. Sta. Rec. 16, p. 978.

[7] Molisch, H. Forcing Plants by Warm Baths. Sci. Amer. Sup. 66 (1908) Exp. Sta. Rec. 20, p. 640.

[8] Iraklionow, P. P. Ueber den Einfluss des Warmbads auf die Atmung u. Keimung der ruheden Pflanzen. Jahr. f. wiss. Bot. 51, pp. 515-540.

[9] Klebs, G. Ueber die Rhythmic in der Entwickelung der Pflanzen. Bot. Centlb. 119 (1912) p. 426.

In this connection the statement of Fisher[1] is of interest. He claimed that the resting buds of trees cannot be made to grow until a certain minimum of the insoluble starch has been changed "to easily respired and therefore energy yielding material." Johannsen and Pfeffer, however, did not seem to think that the presence of sugar was the determining factor.

Gerrassimow[2] found that ether caused increased growth of *Spirogyra* due to a stimulation of the cell nucleus. Latham[3] found an increased economy in the metabolism after increased growth of chloroformed fungi. According to Butkewitsch[4] ether vapor dissolves starch in the leaves. Lepeschkin[5] found that the osmotic pressure of *Spirogyra* cells which remained in .05 per cent to 1 per cent chloroform, or in 2.5 per cent ether solution for some time was increased by 0.1 to 0.5 atmospheres. Zaleski[6] showed that etherization increased the protein regeneration in the cotyledon of *Lupinus* seedlings, diminishing the loss of glucose and causing a greater movement from endosperm into the growing plant.

NORMAL ACTIVITIES OF RESTING PARTS

By first considering the normal physiological behavior of resting parts in plants, the later discussion of "abnormal" physiological processes, such as those produced by the various means used to break the rest period, will be better understood.

Plants or plant parts in a state of "rest" are by no means inactive. Cuttings of hardwood plants made in winter, form callus tissue even tho the buds are incapable of growing. The reserve substances in trees undergo very extensive changes during the course of the winter. Fisher's[1] investigations well illustrate this transformation. In autumn, the parenchyma is filled with starch. During late autumn the starch is transformed to fats and, in part, to glucose. In some cases this change occurs in the cortex only, the starch in the remaining tissues being unchanged; in other cases, no starch can be found during midwinter. Starch is reformed during early spring, and soon reaches a maximum equal to that of the previous autumn. When the buds open the starch is again dissolved to be used in building up new tissues. The reserved food in the buds also undergoes a marked change. Part is transferred to the embryonic organs which at first were free from starch. Quantitative analyses of *Castanea* wood made by Leclerc du Sablon substantiated these observations. This investigator found that the sugar content in October was 2.2 per cent. By February it had increased to 4.3 per cent. A month later the quantity of sugar was again reduced to 2.7 per cent. Chandler[2] found the greatest amount of dextrose in apple twig sap in December. The sap becomes poorer and poorer in sugar until in May.

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[1] Fisher, A. Beiträge zur Physiologie der Holzgewächse. Jahrb. f. wiss. Bot. (1891) 22, pp. 60-73.

[2] Gerrassimow, J. Aether-Kulturen von *Spirogyra*. Flora 94, pp. 16-26.

[3] Latham, Marion E. Stimulation of *Sterigmatocystis* by Chloroform. Bul. Torrey Bot. Club 32, pp. 337-351.

[4] Butkewitsch, W. Upon the Occurrence and Function of Proteolytic Enzymes in Germinating Seeds. Ber. d. d. Bot. Ges. 18 (1900) pp. 358-364.

[5] Lepeschkin, W. W. Effect of Anesthetics Upon *Spirogyra*. Ber. d. d. Bot. Ges. (1911) 29, p. 355.

[6] Zaleski. Zur Aetherwirkung auf die Stoffumwandlung in den Pflanzen. Ber. d. d. Bot. Ges. 28 (1911) pp. 292-296.

Since reproductive and chemical activities continue to take place in resting plants, it might be expected that they also respire. The experiments to be described in succeeding pages of this report throw considerable light on the normal as well as stimulated respiration. In general, the respiratory activity in plants is diminished during the resting period, but CO_2 production continues to go on at all times. Hence it may be said that the rest period is not a stage of complete inactivity as many physiological functions continue. Their activity, however, is reduced and is also dependent upon external conditions to some extent.

RESPIRATION EXPERIMENTS

It has been known for some time that anesthetics and "poisons" in general stimulate the respiratory processes of plants. Likewise mechanical injury, high temperature and other agents are known to bring about greater CO_2 production. This is true of resting as well as active tissue.[3]

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[1] Fisher, A., Beitrage zur Physiologie der Holzgewächse. Jahrb. f. wiss. Bot. (1891) 22, pp. 60-73.

[2] Chandler, W. H., Sap Studies of Horticultural Plants. Mo. Agr. Exp. Sta. Research Bul. 14.

[3] Simon, S. Untersuchungen über das Verhalten einiger Wachstums funktionen sowie die Atmungs tatigkeit der Laubhölzer während der Ruhperiode Jahrb. f. wiss. Bot. 43 (1906) pp. 1-48.

Iraklionow, P. P. Ueber den Einfluss des Warmbads auf die Atmung u. Keimung der ruhenden Pflanzen. Jahr. f. wiss. Bot. 51, pp. 515-540.

Butler, O. A Note on the Significance of Sugar in Tubers of *Solanum tuberosum*. Bul. Torrey Bot. Club 40 (1913), p. 110.

Object of the Experiments. During these studies, conducted in 1913-14, respiration experiments were carried out with the following objects in view:

1. To determine the effect of previous drying and of previous freezing on the CO_2 production of dormant apple twigs.
2. To determine the influence of the same dose of ether on the CO_2 production of dormant twigs of different species.
3. To determine the effect of the same dose of ether on the CO_2 production of dormant apple twigs at different times during the season.

Method of Collecting Material. The importance of obtaining representative material and uniform lots for comparative experiments, was carefully considered. The plan of securing twigs for the experiments was as follows: In all cases, one-year-old twigs, i. e., the growth which had been made during 1913, were used. This material had been exposed to the environment the shortest time, and hence had not as much chance to become altered in one way or another as older material. The twigs used were fully matured, each specimen having formed a normal terminal bud. They were taken from the tops of the trees where all had had the same exposure to sunlight and other conditions. Only those twigs which had made from 20 to 30 cm. growth were collected. They were cut from the tree just above the last annual ring. Where twigs were obtained from more than one tree, the material from each tree was kept separate until divided into lots. When a series of comparative experiments was to be made, the material was secured from the same trees, and just as much was taken from every tree as was used from that particular tree in the other tests. For example, if material was secured from trees Nos. 1, 2, 3, etc., each tree yielding fifty twigs, when the same experiment was to be repeated a few weeks later, fifty twigs would be collected from each of trees Nos. 1, 2. 3, etc.

After the material was secured, the samples from each were divided into similar lots in the following manner: All the cut surfaces of the twigs were placed down, the terminal buds up. The bunch of twigs was held loosely between the hands, and then jolted up and down on the table until all cut ends stood on the same level. Then the lot was held with one hand, and with the other, the twigs were distributed one at a time commencing with the longest and ending with the shortest. If the material from each tree was divided among six lots, Nos. 1, 2, 3, 4, 5 and 6, then No. 1 would receive the first twig, and No. 6, the sixth; the seventh twig would go to No. 6 and the twelfth and thirteenth to No. 1, etc. When the material from the second tree was distributed, No. 6 received the first and No. 1 the sixth and seventh, etc. The material from each tree was distributed in a similar manner. In the end, these composite samples were almost exactly alike. Each contained the same number of twigs; each had just as many twigs from any single tree as the other; and every lot had just as many long and just as many short twigs as the others. The efficiency of this method of distribution was shown by the fact that the weights of the composite samples obtained in this way never varied more than 2 or 3 per cent. Incidentally, it was considered necessary to have the same number of twigs in each lot, because each twig had received a wound and wounding affects respiration. Altho other precautions were taken to offset the effects of this wounding, still if the precautions were not entirely adequate, then the effect on respiration by the injury would be the same in all lots, and the results would still be comparative.

Apparatus. The general appearance of the apparatus used for the determination of the CO_2 production of the twigs, is shown in Fig. 1. The respiration chambers proper consisted of six slender specimen jars. Each chamber with its accompanying parts formed a single unit. The diagram shown in Fig. 2 illustrates in detail the construction of one of these units. The chamber "5" had a capacity of 2.5 liters. Before the air entered this chamber, it was freed from CO_2 by passing tho the saturated solution of KOH in tube "6." It left the chamber, together with the CO_2 produced by the twigs, thru the glass tube "13" which opened at the bottom of the jar. The moisture was taken up by the $CaCl_2$ in tube "14." The CO_2 produced by the twigs was absorbed by the saturated solution of KOH in the Geissler bulbs "7". A $CaCl_2$ tube "8" retained all moisture which evaporated from the bulbs.

In setting up the apparatus, the weighed twigs were placed in chamber "5" after which the two-hole cork was inserted. Then the glass tubes for the incoming and for the outgoing air were passed thru the cork. The KOH and the $CaCl_2$ tubes were connected to the respective glass tubes. After this a strip of heavy paper (2) 6 cm. wide, was tightly wrapped around the glass flange at the top of the jar. This paper form was held firmly by means of a rubber band. Melted paraffin was then poured over the cork to a depth of from 1 to 2 cm. This sealed all possible openings thru which there might be leakage of air.

The absorption bulbs were connected by means of rubber tubing. They were weighed on a delicate balance.

After all units were set up in a similar manner, they were connected to the same sensitive system. The air was drawn thru each chamber at an avergae rate of three liters per hour, the flow being regulated by means of the thumb screw at "15" (Fig. 2). Each day the air contained in every unit was renewed eight times, which was proven by experiment to be sufficient to obtain all the CO_2 produced by the twigs during twenty-four hours. Suction was provided by a large aspirator bottle. This bottle had a capacity of forty-five liters. Just before the air entered the water bottle, it passed through a $CaCl_2$ tower. The $CaCl_2$ retained all moisture which came from the bottle, and which, if not removed, would be taken up by the $CaCl_2$ tubes attached to the absorption bulbs, thereby increasing their weight unduly.

The entire apparatus, excepting the aspirator, was placed in a large double-walled box made of heavy galvanized iron (Fig. 1). The space between the two walls (5 cm.) was filled with water which was flowing in and out continually. The doors were also double-walled but they contained no water. The edges of the doors were lined with cotton so they would fit tightly and thereby prevent exchange of air of different temperatures. The box was placed in a cool north basement room.

A self-recording thermograph within the box showed an almost horizontal line from day to day. The thermometer registered between 15° and 18° C.

EXPERIMENT 1. CO_2 PRODUCTION OF TWIGS AS INFLUENCED BY PREVIOUS DRYING AND BY FREEZING

On February 14, 1914, twigs from three King David apple trees were collected and divided in the manner described above. Two lots were placed in a freezing apparatus as shown in the diagram, Fig. 3. The temperature was kept at -15° to -19° C. Two lots were placed in a humidor at room temperature, 18° to 21° C. (See diagram, Fig. 3.) Two lots were placed on top of a bookcase where the room temperature varied between 26° and 31° C. In all cases the preliminary treatment lasted sixty hours. Before placing in the respiration chamber, the dried twigs were allowed to regain turgidity by immersing them in water for several hours. During that time they imbibed enough moisture to bring them up to within 5 per cent of their original weight.

The data of this experiment are summarized in Tables 1 and 2. The dates show when the material was collected. Calculations of CO_2 production are based on the weights of the twigs just before they were put in the respiration chambers. If the calculations had been made on fresh weight, the results would have been affected relatively little. It should be kept in mind that while the dry twigs had lost nearly one-fourth of their weight, that this was made up again before putting the material in the chamber. The KOH bulbs were weighed every twenty-four hours and from this the results were reduced to a one-hour basis.

TABLE 1—CO_2 PRODUCED BY MOIST, BY DRIED AND BY FROZEN KING DAVID APPLE TWIGS AT 15° to 19° C.

Date	Treatment	Av. Wt. fresh twigs	H_2O lost during treatment	CO_2 production in Mg. per hr. per 100 gr. twigs			
				1st da.	2nd da.	3rd da.	4th da.
Feb. 14	Moist	116.1 gr.	3.9%	2.79	3.57	2.73	1.83
Feb. 14	Dried	117.0	22.6	8.56	10.34	6.43	4.39
Feb. 14	Frozen	115.9	1.8	12.16	8.65	4.74	3.84

The figures in Table 1 show that the frozen twigs produced more CO_2 during the first day than either the dried or the moist material. After that the dried twigs took the lead. Both the moist and the dry twigs produced more CO_2 the second day than the first, but the frozen twigs produced less. After the second day, the respiratory activity diminished in all cases.

TABLE 2—RATIO OF CO_2 PRODUCED BY TREATED TO CO_2 PRODUCED BY MOIST TWIGS

	1st da.	2nd da.	3rd da.	4th da.
Dried, moist........................	3.07	2.89	2.36	2.40
Frozen, moist........................	4.36	2.42	1.73	2.10

Table 2 gives the ratio of the CO_2 produced by the treated to the CO_2 produced by the moist twigs. The figures are obtained by dividing the amount of CO_2 produced per 100 gr. treated twigs, per hour, by the amount of CO_2 produced by 100 gr. untreated or moist twigs per hour.

During the first day, the frozen twigs produced more than four times as much CO_2 per hour, per 100 gr. of twigs as the twigs kept moist. The dry twigs gave off three times as much. The ratios fell on the second and third days in both cases; but on the fourth day they rose again. These figures show that the decline in the respiratory activity of the twigs kept moist went on more slowly and more uniformly than either of the treated sets. The figures also show that the respiration of the dried twigs noticeably decreased day by day, while the respiratory activity of the frozen material was not nearly so marked on the third day as it was on the first two days.

In this connection it should be mentioned that all buds on the twigs which were given the preliminary treatment and then placed in beakers of water in the greenhouse, burst within a few weeks. The frozen twigs were a little ahead of the dried ones in beginning growth and both were about one week ahead of those that were untreated.

EXPERIMENT 2. CO_2 PRODUCED BY ETHERIZED AND BY UNTREATED TWIGS OF DIFFERENT SPECIES

The species used in these experiments were *Pyrus malus*, Linn., *Fraximus Ornus*, Linn., *Quercus coccinea*, Muench, and *Morus alba*, Linn. One-year-old wood from young vigorous trees was used in all cases. The twigs were collected and arranged in lots as previously described. Preliminary treatment was carried out in the following manner: The six lots were placed in two 14-liter specimen jars, as shown in Fig. 4, three lots in each jar. The jars were provided with screw clamp lids and rubber washers by means of which they could be made air-tight. Just before fastening the lid of one of the jars, ether at the rate of 0.5 cc. per liter of space, was poured in. The lid was then screwed on immediately. The other jar was closed up without adding any ether. The vessels were kept side by side for twenty-four hours at a temperature of 20° C.

Since neither jar contained water, no allowance had to be made for absorption of ether by water.[1] The absence of water gave the cut ends of the twigs a chance to become dry and plugged up. This no doubt tended to minimize, tho not to entirely do away with, the effect of injury on respiration. However, since the same number of twigs were contained in each lot, error from this source would be the same in all cases and hence its influence would not affect the comparative value of the results.

The moisture lost during this preliminary treatment was practically the same in both etherized and unetherized material, the amount lost never exceeding 0.5 of 1 per cent. (See Table 3). The moisture lost was from transpiration.

As soon as the preliminary treatment was over, the twigs were placed in the respiration chamber and CO_2 determinations began.

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[1] Johannsen, W. Das Aetherverfahren beim Frühtreiben, etc. Zweite Anfl. Jena 1906.

The results obtained are summarized in Table 3. The dates in the table show when the twigs were collected. Calculations were based on the fresh weight which was practically the same as the weight after the preliminary treatment. The KOH bulbs were weighed once every twenty-four hours.

TABLE 3—CO_2 PRODUCED BY ETHERIZED AND UNTREATED TWIGS OF DIFFERENT SPECIES, AT 15-18° C.

Date	Species	Treatment	CO_2 production in Mg. per 100 gr. twigs		
			1st da.	2nd da.	3rd da.
Jan. 7	*Pyrus malus*, Linn.	Etherized	19.51	12.01	9.39
		Untreated	6.55	3.51	2.65
Jan. 13	*Fraxinus Ornus*, Linn.	Etherized	4.76	7.15	4.76
		Untreated	3.60	6.27	3.57
Jan. 19	*Quercus coccinea*, Muench	Etherized	14.29	9.24	7.83
		Untreated	8.35	4.60	4.01
Jan. 23	*Morus alba*, Linn.	Etherized	41.19	25.77	14.09
		Untreated	17.52	12.15	8.03

Discussion of Results. From the data it is seen that the normal respiration of different species varies greatly, being most vigorous in the mulberry, next highest in the oak and least in case of the ash and apple. In all cases etherization caused an increased production of CO_2. The relative amount of increase, however, varied with the different species, as may be seen by comparing the ratios given in Table 4. These ratios were obtained in the manner previously explained.

TABLE 4—RATIO OF CO_2 PRODUCED BY ETHERIZED, TO CO_2 PRODUCED BY UNTREATED TWIGS

	1st da.	2nd da.	3rd da.
Pyrus malus, Linn.	2.98	3.43	3.54
Fraxinus Ornus, Linn.	1.32	1.14	1.33
Quercus coccinea, Muench	1.71	2.01	1.95
Morus alba, Linn.	2.39	2.12	1.75

The figures show that the stimulating effect of ether was most marked in case of the apple, the etherized material having produced more than three times as much CO_2 as the untreated. The ratio greatly increased from the first until the third day. In mulberry, etherization did not cause such a great increase in CO_2 production as in the apple, but it was greater than with ash or oak. The increase was greatest during the first day after which it became less noticeable.

The respiration of oak twigs was affected less by etherization than that of either apple or mulberry. The stimulation seemed to increase from the first to the third day. Etherized ash twigs did not give off very much more CO_2 than untreated twigs.

In all cases etherized and untreated twigs were placed in the greenhouse in beakers of water where they were allowed to grow. The treated apple buds came out more than a week earlier than the untreated; in case of the mulberry, the etherized buds came out several days before the untreated, but they soon stopped growing, allowing the untreated buds to overtake them. The etherized and untreated oak and ash buds opened about the same time. Treatment apparently had no effect.

It was noticeable that the species in which CO_2 production was stimulated most by etherization, opened their buds before the untreated. When the stimulation continued to increase for several days, there was no reaction in the development of the young growth; but when the stimulation declined very quickly a reaction did occur. When respiration was stimulated but very little, the treatment had little effect in causing the buds to open earlier.

EXPERIMENT 3. CO_2 PRODUCED BY ETHERIZED AND BY UNTREATED APPLE TWIGS AT DIFFERENT TIMES DURING THE SEASON

The material for this series of experiments was secured from a number of thrifty fifteen-year-old Jonathan apple trees of similar vigor, which were growing in the Agricultural Experiment Station orchard at Columbia, Missouri. The twigs were collected and divided into lots as previously described. The lots contained about 40 twigs each and weighed about 150 grams.

The preliminary treatment with ether was carried out in the same way as described in the previous experiment. Immediately after the preliminary treatment, the material was put in the respiration chambers and CO_2 determinations begun at once.

The dates on which the material was collected, as well as the results of the CO_2 determinations, are given in Table 5. Calculations were based on the fresh weight of the twigs. In all cases the figures are averages of three samples which represented over 400 gr. of material. The KOH bulbs were weighed once every twenty-four hours.

TABLE 5—CO_2 PRODUCED BY ETHERIZED AND BY UNTREATED JONATHAN APPLE TWIGS AT VARIOUS TIMES DURING THE DORMANT SEASON. TEMPERATURE 15-18°C.

Date	Treatment	CO_2 production in Mg. per hr. per 100 gr. twigs					
		1st da.	2nd da.	3rd da.	4th da.	5th da.	6th da.
Oct. 23	Etherized	10.40	5.72	3.50	2.96	....	....
	Untreated	8.38	5.17	3.19	2.77	....	....
Nov. 26	Etherized	31.36	13.52	8.37	7.22	5.24	3.70
	Untreated	19.91	5.31	3.10	3.13	2.30	2.31
Jan. 8	Etherized	19.51	12.01	9.39	....	5.31*	4.87
	Untreated	6.55	3.51	2.65	....	2.12*	1.75
Feb. 9	Etherized	20.33	13.64	8.23	5.59	1.39	.57
	Untreated	8.75	6.05	3.79	3.87	2.46	2.41
Mar. 8	Etherized	21.89	13.18	7.37	2.03	1.25	.72
	Untreated	7.52	5.61	4.42	4.55	5.06	4.57

*Average for 4th and 5th days.

The data are shown graphically in the form of curves in Fig. 6. The mg. of CO_2 produced by 100 gr. twigs per hour, are laid off on the vertical and the days of the experiment on the horizontal. The points are located half way between the beginning and the end of the days, and not at the end of the day when the bulbs were weighed. This was done because the points are averages of twenty-four hours being reduced to a one-hour basis from weighings made once a day. The Roman numerals indicate the number of the experiments. The dates on which these experiments were started are indicated in the right-hand corner of the figure. The curves labeled "*a*" show the CO_2 production of etherized twigs; those labeled "*b*", of the untreated material. I*a* and I*b* show the curves of CO_2 production of etherized and of untreated twigs respectively during Experiment I which was started on October 23, 1913. Similarly II*a* and II*b*, III*a* and III*b* are parallel pairs.

A study of Fig. 5 shows that in all cases the etherized material gave off more CO_2 during the first few days than the untreated whose CO_2 production was determined at the same time, i.e., I*a* gave off more than I*b*; II*a* more than II*b*, etc.

A more detailed examination show that the individual etherization curves differ markedly both in their location with respect to the curves of the untreated twigs as well as in the amount of curvature. In Experiment I, *a* is but very little above *b*, and both curves run nearly parallel to each other. In II, *a* is considerably above *b*.

In both cases the CO_2 production fell off very rapidly during the first two days. So far as known, the experimental conditions were exactly the same during these days as during the remaining days, and also similar to the conditions under which the other CO_2 determinations were made. The decline in *a* and *b* became less marked after the second day. The former fell somewhat more than the latter.

In III, *a* is far above *b*. Curve III*b* is the lowest of the curves for CO_2 production of untreated twigs. This determination was made on January 8, in the middle of the dormant season when the normal activity might be expected to be very low. Curve IV*a* started out much above IV*b*, the one it is compared with, but declined fairly uniformly until it actually went below the latter during the fifth day. This curve departed from the behavior shown by I*a*, II*a*, and III*a*. All these curves declined much more rapidly during the first day than thereafter, and none of them went below the respective *b* curves during the time of the experiment. Curve V*a* behaved somewhat like IV*a*. It declined even more uniformly, intersecting V*b* at the end of the third day. Curve V*b* declined less rapidly during the first day than any other curve. After the third day it was higher than any other *b* curve. This determination was made late in the season. The buds, however, were still dormant, but judging from the behavior of the CO_2 production, they had passed their rest period and were held back only by unfavorable weather conditions.

Some of the points to which attention has been directed are brought out more clearly in numerically expressed ratios between the CO_2 production of etherized and untreated material. These ratios are given in Table 6. The values were obtained in the manner explained before. The last column of the table gives the averages of all the ratios.

TABLE 6—RATIO OF CO_2 PRODUCED BY ETHERIZED, TO CO_2 PRODUCED BY UNTREATED TWIGS

Date	1st da.	2nd da.	3rd da.	4th da.	5th da.	6th da.	Average
Oct. 23...........	1.24	1.10	1.09	1.07	....	....	1.13
Nov. 26...........	1.58	2.55	2.71	2.31	2.28	1.60	2.17
Jan. 8...........	2.98	3.43	3.54	....	2.50*	2.78	3.05
Feb. 9...........	2.32	2.25	2.17	1.45	.56	.23	1.48
Mar. 8...........	2.91	2.35	1.67	.45	.25	.16	1.30

* 4th and 5th days.

The data in Table 6 are represented graphically by the curves in Fig. 6. The ratios in the left hand portion of the figure are laid off on the vertical, the days of experiment on the horizontal. Roman numerals here as before represent the numbers of the experiments which were performed on the dates given in the upper part of the figure. The heavy horizontal line 1.00 represents the amount of CO_2 produced by the untreated twigs.

Curve I is only a little above the line for the untreated material Curve II starts out higher than I. It ascends until it reaches a maximum during the third day after which it begins to decline. Curve III starts out much higher than either I or II. It behaves somewhat like II in that it rises until the third day after which it begins to decline. Curve IV starts out over twice as high as III. It declines from the start, at first slowly then more rapidly. It finally cuts line 1.00 during the latter part of the experiment. Curve V starts out rather high but it goes down very rapidly falling below line 1.00 even before IV.

The nearer the close of the dormant season, the shorter was the period during which the etherized twigs produced more CO_2 than the unetherized material.

In the right hand portion of Figure 6, the numbers of the experiment are laid off on the horizontal. Since the experiments were performed approximately one month apart, the points also indicate the various dates during the season.

Curve A was obtained by plotting the data in the last column of Table 6. This curve again shows that during the early part of the season etherization exerts relatively little influence toward increasing the CO_2 production of dormant twigs. This is shown by the proximity of the point I to the line 1.00. A month later the effect of ether was much more apparent. About the first of January the maximum stimulation was obtained. After another month, the stimulating effect of ether became less. It was still less after another month. Curve B in which the ratios obtained on the third day of each experiment are plotted, brings out the same facts.

In connection with each experiment etherized and untreated twigs were put in beakers of water and placed in the greenhouse where they were allowed to grow. In general, the results obtained were similar to those given by other investigators. During the first part of the season the twigs grew with difficulty. At first etherization did not cause an earlier growth but later on growth did commence rather sooner than in untreated material. When the stimulation of CO_2 was most marked, the etherized twigs grew very quickly, several weeks ahead of the untreated. In the latter part of the season the etherized specimens came out only a few days ahead of the untreated, and in the last experiment, the untreated twigs outgrew the etherized ones even tho the latter opened a day or two before. These forcing results with apple twigs are very similar to those given by Johannsen[1] for bulbs.

The results of these respiration experiments are discussed on page 45.

EXPERIMENTS ON ENZYME ACTIVITY

It is known that enzymes will become inactive if the products of their work are not utilized in some way or other.[2] As Klebs[3] points out, the leaves of many plants continue to elaborate food in autumn for some time after length growth has ceased. As a result, the assimilated food accumulates so that the work of the ferments is greatly hindered until they finally become entirely inactive. As previously stated, Klebs believed that every rest period can be broken if it is found possible to arouse enzymic activity. Do agents which break the rest period have an effect on the enzyme activity of the twigs? The object of the following experiments was to determine just what effect some of the principal rest period breaking agents have on these ferments.

Experimental Material, Methods, etc. For the most part, one-year-old apple twigs were used in these experiments. In a few cases older wood was made use of. The material was taken from vigorous Jonathan, Ben Hur, Ben Davis, Payne's Keeper, Red June and Nixonite apple trees, growing in the station orchard at Columbia, Missouri. The enzyme activity of one-year twigs of Quercus coccinea, Fraxinus Ornus, Forsythia suspensa, and Prunus Persica was also determined.

Method of Collecting. The method of collecting the one-year twigs and then dividing them into similar lots was the same as heretofore described. To obtain comparable samples of old wood, alternating sections of the same branch were used for treated and for untreated material, respectively. When the enzyme activity of buds alone was to be tested, large branches containing an abundance of spurs were collected. These were then cut into smaller parts. Similar parts growing adjacent to each other were divided into lots to be treated and lots which were to remain untreated.

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[1] Johannsen, W. Das Aetherverfahren beim Frühtreiben, etc. Zweite Anfl. Jena 1906.

[2] Pfeffer, W. Pflanzenphysiologie Bd. II. 1904. Especially the chapter on Periodicity.

[3] Klebs, G. Ueber die Rhythmik in der Entwickelung der Pflanzen. Bot. Cantbl. 119 (1912) p. 426.

Agents Employed. The agents employed to break the rest period were etherization, drying, warm water bath, alcohol bath, hydrochloric acid bath, sodium nitrate spray, and mechanical injury. The strength as well as the duration of the treatments are given in the tables. Etherization was carried out as previously described.

Suitable checks were used in all cases. For example, if treated twigs were being bathed in alcohol, the untreated or check twigs were immersed in pure water during the same period. This was done to equalize as far as possible any effect that exclusion of free oxygen from the twigs might have on the enzyme activity of the tissue. Similar precautions were taken in case of checks for other forms of treatment.

The enzyme activity was determined either immediately after the close of the period of application of the treatment, or after an interval of one or more days. During this interval the twigs were kept standing at room temperature in beakers containing about 50 cc. of tap water.

Preparation of Material. The outer fleshy parts only were used to determine the enzyme activity of the twigs. This fleshy portion, including the cortex proper, the bast layer, the cambium and more or less of the sap wood as well as the lateral and terminal buds, as a matter of convenience, are listed in the table under the heading of "cortex." The term is used very loosely. The buds alone would have been best for the enzymatic tests, but it was very difficult to obtain material of this kind in sufficient quantities. The hard, woody part of twigs is very low in enzymic activity. Hence the choice of the fleshy portions.

The "cortex" was scraped from the twigs with a knife. The shavings thus secured were then finely ground in a common kitchen meat chopper. The chopper sheared the tissue into fine particles but did not squeeze out the juice unless the material was very succulent. The mass after grinding was very uniform thruout.

When buds alone were used to determine the enzyme activity, the entire buds together with about 3 to 5 cm. of the spurs on which they grew were ground up. Several 5 gr. samples of each kind of material were carefully weighed out and placed in glass vials.

1. **Diastatic Activity.** The first test was for diastatic activity. To each vial of the cortex was added 25 cc. of a 2 per cent potato starch paste. The starch paste was made by adding 90 cc. of boiling water to 2 gr. c. p. potato starch which had been wet with 10 cc. of cold water. After cooling, 2 per cent toluene was added to this paste.

The amount of starch solution added to the vial was just sufficient to cover the 5 gr. of cortex so that all material had a chance to act, and all starch was exposed to action by the ferments. As soon as the starch was added and mixed with the mass of cortex material, the vials were put in an incubator at a temperature of 35° C.

At intervals of one or two hours, the material in each vial was again thoroly mixed by stirring with a clean glass rod. Later ½ to 1 cc. of the liquid from each sample was removed by means of pipettes and placed in a number of Syracuse watch glasses. Two watch glasses were used for each sample. The watch glasses, which had flat bottoms, were placed on a white surface near a good natural light. A few drops of iodine solution were added to the liquid in each glass. Whenever the color produced by the addition of the iodine faded out, more iodine was added until a permanent color was obtained. Care had to be taken not to add too much iodine as this would have obscured the color.

Iodine added to starch produces a characteristic blue color. If starch has been subjected to the action of a starch-changing ferment, such as diastase, for a time, then the addition of iodine no longer produces a blue color, but instead a blue-purple or violet, red-purple, red, red-brown, yellow-brown or no color at all. The particular color obtained depends upon the amount of enzyme which is acting, and upon the time it is allowed to act if temperature and other factors are constant. If a given amount of ferment acts on starch for a short time, then a blue-purple color is obtained by adding iodine; if it acts for a very long time, there is no color reaction. If a very small amount of enzyme acts on starch for a given time, there will be a blue-purple reaction with iodine at the end of that time. A much larger quantity of ferment acting on the same amount of starch for the same time may give a red-brown reaction. Since the color obtained with iodine indicates the degree to which starch has been changed,[1] and since the enzymes are responsible for the change, then the color obtained at the end of a definite time will serve as a basis for measuring the enzyme activity. In these experiments the colors obtained at each trial were carefully recorded. All determinations were made in duplicate except in a few cases where the material was too scarce. In practically every case the duplicates showed the same reaction.

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1. Green, J. Reynolds. The Soluble Ferments and Fermentation. (2nd Ed. Cambridge 1901).

It should be mentioned here that all the observations on colors were corroborated by the judgments of two or three persons who knew nothing about the details of the experiment.

To make the results comparative, seven easily recognized colors were taken as a standard. Water color reproductions of these are shown in Fig. 7, in the order in which they may be obtained. Each color was numbered beginning with 1 and ending with 7. These numbers are used in the tables. The smaller the number, the less the enzyme activity; the greater the number, the more active the ferments. (See Fig. 7, p. 63).

That the changes occurring in the experiments were due to enzymes contained in the tissue was taken for granted from the fact that whenever the tissue was heated to 100° C. for a few minutes and then allowed to act on starch paste, no change occurred. The reaction with iodine was the characteristic blue thruout the time of the experiment. The rapid conversion of the starch[1] and the fact that toluene was added to prevent organisms from developing, eliminates bacterial activity as being responsible for the changes noted when unheated material was allowed to act.

This method of determining the comparative enzyme activity is, of course, not free from objections. A probable source of error is found in the fact that many substances were dissolved from the tissue in addition to the enzymes. Some of these substances, e. g., tannin may hinder to some extent the free action of the enzymes. However, it is likely that the same amount of these inhibiting factors were present in both check and treated material, so that the comparative value of the results remain unaffected. Again, the results were not as quantitative as might have been desired. On the whole, however, the methods outlined gave very satisfactory results for these preliminary experiments. The simplicity of the tests and the reliability of the results are points in favor of the method.

The results obtained with the diastatic enzyme experiments are summarized in Tables 7 to 11. In all cases, the dates show when the material was collected. Enzyme activity was determined after two and after four hours. This activity is expressed in numbers which are based on color reactions as previously explained. It should be kept in mind that the greater the number, the greater the enzyme activity. The plus sign after the numbers indicates that the color was close to the next more advanced; the minus sign indicates that the color barely passed the less advanced. For example, 2 — and

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[1] Bayliss, W. W. The Nature of Enzyme Action. (Longmans, Green, & Co. 1911).

2+ indicate that both gave blue-purple reaction with iodine; 2− however, had little purple and much blue, while 2+ was almost but not quite, red-purple. The abbreviations "Untr." and "Tr." stand for untreated and treated, respectively. The other terms in the table are self explanatory.

The data in Table 7 shows that the agents which are known to break the rest period, also increased the diastatic enzyme activity

TABLE 7—STIMULATION OF DIASTATIC ENZYME ACTIVITY OF DORMANT TWIGS OF PYRUS MALUS AND OTHER SPECIES BY TREATMENTS GIVEN TO BREAK THE REST PERIOD

No.	Date	Kind of Twigs	Treatment	Interval Hrs.	Enzyme activity			
					2 hrs.		4 hrs.	
					Untr.	Tr.	Untr.	Tr.
1	Oct. 14	Jonathan Apple	0.5 cc. Ether 24 hrs.	0	2	3	3	5+
2	Nov. 10	Jonathan Apple	0.5 cc. Ether 24 hrs.	48	3−	3+	3+	6
3	Dec. 13	Jonathan Apple	0.25 cc. Ether 24 hrs.	10	4	5	6	6
4	Mar. 4	Jonathan Apple	0.25 cc. Ether 24 hrs.	16	5	6	7	7
5	Oct. 17	Jonathan Apple	H_2O 35° C. 15 hrs.	0	..	..	3+	4
6	Oct. 12	Jonathan* Apple	0.5 cc. Ether 48 hrs.	0	3	4	5	6
7	Oct. 28	Jonathan* Apple	Injured **	96	3	5	4	7
8	Dec. 2	Jonathan* Apple	10% C_2H_5OH 15 hrs.	30	2	3	3	4
9	Mar. 12	Jonathan* Apple	10% Na NO_3 Spray	150	6	7	3‡	5‡
10	Mar. 3	Ben Hur Apple	Dried, 35° C. 15 hrs.	48	4+	6	7	7
11	Dec. 9	Ben Hur Apple	10% C_2H_5OH 9 hrs.	15	3	3+	5−	6
12	Feb. 24	Ben Hur Apple	0.5 cc. Ether 20 hrs.	48	3+	6	6	7
13	Mar. 2	Ben Hur Apple	0.25 cc. Ether 24 hrs.	15	3+	4	6	7
14	Dec. 6	Nixonite Apple	0.5 cc. Ether 24 hrs.	18	3+	4	5	6
15	Jan. 11	Nixonite Apple	0.5 cc. Ether 24 hrs.	0	2−	2+	2+	4
16	Feb. 21	Red June Apple	0.25 cc. Ether 24 hrs.	20	4	6	5	7
17	Feb. 27	Red June Apple	10% C_2H_5OH 15 hrs.	0	3−	3+	3+	5
18	Nov. 17	Payne's Keeper Apple	Dried 40° C. 6 hrs.	60	..	..	3	4
19	Nov. 17	Payne's Keeper Apple	Injured†	66	..	..	3	5
20	Feb. 24	Woodmanse Apple	0.5 cc. Ether 24 hrs.	48	2	4	6	7
21	Nov. 24	Ben Davis Apple	0.5 cc. Ether 24 hrs.	24	2+	3	3	4
22	Dec. 15	*Fraxinus Ornus*, Linn.	0.5 cc. Ether 20 hrs.	0	4	6+	7	7
23	Dec. 3	*Forsythia viridissima*, Lindl.	0.25 cc. Ether 24 hrs.	20	2	2+	2+	3

* Buds only used.
** Injured by piercing buds with needle.
† Injured by pounding internodes with knife handle.
‡ After one hour.

of dormant tissue. In every case, the numbers in the column headed "treated" are greater than those in the column for "untreated." The amount of increase obtained varies in different cases depending upon the agent used, the species, variety and other factors. It should not be assumed that stimulation was obtained in all cases. Instances in which the rest period breaking agents have either no effect or even an inhibitory influence will be given in the tables which follow.

TABLE 8—DIASTATIC ENZYME ACTIVITY OF DORMANT TWIGS OF PYRUS MALUS AND OTHER SPECIES AS INFLUENCED BY SAME TREATMENT AT DIFFERENT TIMES OF THE SEASON

No.	Date	Kind of Twigs	Treatment	Interval Hrs.	Enzyme activity			
					2 hrs.		4 hrs.	
					Untr.	Tr.	Untr.	Tr.
1	Oct. 14	Jonathan Apple	0.5 cc. Ether 24 hrs.	0	2	3	3	5
	Nov. 10	....	....	......	3−	2+	5	3
	Mar. 13	....	....	......	5	4−	7	7
2	Nov. 28	Jonathan* Apple	Injured**	96	3	5	4	7
	Mar. 11	....	....	......	4	4+	7	7
3	Jan. 11	Nixonite Apple	0.5 cc. Ether 24 hrs.	0	2−	2+	2+	4
	Mar. 12	....	....	......	3+	3+	7	7
4	Nov. 24	Ben Davis Apple	0.5 cc. Ether 24 hrs.	20	..	..	3	4−
	Mar. 9	....	....	......	3	2	4	2
5	Dec. 10	Ben Hur Apple	0.25 cc. Ether 24 hrs.	18	3+	3+	4	4
	Mar. 2	....	....	......	3+	4−	6	7
6	Dec. 15	*Fraxinus Ornus*, Linn.	0.5 cc. Ether 20 hrs.	0	4	6+	7	7
	Mar. 12	....	....	......	6†	4†	......	......
7	Dec. 21	*Quercus coccinea*, Meunch	0.5 cc. Ether 24 hrs.	0	2	2	2+	2+
	Mar. 12	....	....	......	2−	2−	2+	2+

* Buds only used.
** Injured by piercing buds.
† After 1 hour.

The date of application of the agent is an important factor in the enzyme determinations, as may be seen from the data in Table 8. In some cases the enzymes apparently were not stimulated in the early part of the season; but the same treatment applied a few months later caused increased enzyme activity. (Cf. No. 5, Table 8.) In other cases, a dose of ether proved effective early in the season, while later on, it had very little or no effect whatever. (Cf. 3 and 4, Table

TABLE 9—DIASTATIC ENZYME ACTIVITY OF DORMANT PYRUS MALUS TWIGS AS INFLUENCED BY DIFFERENT INTENSITIES OF THE SAME TREATMENT

No.	Date	Variety	Treatment	Interval Hrs.	Enzyme activity			
					2 hrs.		4 hrs.	
					Untr.	Tr.	Untr.	Tr.
1	Dec. 6	Nixonite	0.5 cc. Ether 24 hrs.	18	3+	4	5	6
			0.25 cc. Ether 24 hrs.	18	3+	3−	5	3+
2	Dec. 13	Jonathan	0.5 cc. Ether 24 hrs.	10	4	4−	6	5
			0.25 cc. Ether 24 hrs.	10	4	5	6	6+
3	Feb. 21	Woodmanse	0.5 cc. Ether 24 hrs.	20	5+	3+	6	5−
			0.25 cc. Ether 24 hrs.	20	5+	6	6	6+
4	Feb. 21	Red June	0.5 cc. Ether 24 hrs.	20	4	3+	5	6
			0.25 cc. Ether 24 hrs.	20	4	6	5	7
5	Feb. 21	Payne's L. K.	0.5 cc. Ether 24 hrs.	20	5−	2	6	3
			0.25 cc. Ether 24 hrs.	20	5−	3	6	4
6	Mar. 2	Ben Hur	0.5 cc. Ether 24 hrs.	15	3+	3−	6+	6−
			0.25 cc. Ether 24 hrs.	15	3+	4−	6+	7
7	Mar. 4	Jonathan	0.5 cc. Ether 24 hrs.	16	5	3	7	6+
			0.25 cc. Ether 24 hrs.	16	5	6	7	7
8	Mar. 2	King David	0.5 cc. Ether 24 hrs.	15	3+	2	6	4
			0.25 cc. Ether 24 hrs.	15	3+	3	6	5
9	Feb. 27	Red June	10% C_2H_5OH 15 hrs.	0	3−	3+	3+	5
			20% C_2H_5OH 15 hrs.	0	3−	3−	3+	3+
10	Dec. 9	Ben Hur	Dried 35° C. 7 hrs.	17	3	3	5	5
			Dried 35° C. 18 hrs.	6	3	2+	5	3
11	Dec. 10	Ben Hur	H_2O 35° C. 3 hrs.	19	2+	2+	3−	4−
			H_2O 35° C. 6 hrs.	16	2+	2+	3−	4+
			H_2O 35° C. 9 hrs.	13	2+	2+	3−	5

8). In still other cases the late treatment actually caused the enzymes in the tissue to become less active than those in untreated material. (Cf. 1, 4 and 6, Table 8). Attention should be called to the fact that in practically all cases, the enzyme activity of the untreated twigs increased as the season advanced.

The enzymes in the oak did not seem to be affected by the particular treatment given them.

TABLE 10—DIASTATIC ENZYME ACTIVITY OF DORMANT PYRUS MALUS TWIGS AS INFLUENCED BY THE INTERVAL AFTER TREATMENT

No.	Date	Variety	Treatment	Interval Hrs.	Enzyme Activity 2 hrs. Untr.	Enzyme Activity 2 hrs. Tr.	Enzyme Activity 4 hrs. Untr.	Enzyme Activity 4 hrs. Tr.
1	Oct. 26	Jonathan	0.5 cc. Ether 24 hrs.	0	3	3−	3+	3
				14	2	5	3+	7
2	Nov. 10	Jonathan	0.5 cc. Ether 24 hrs.	0	3−	2+	5	3
				48	3−	3+	4	6
3	Mar. 13	Jonathan	0.5 cc. Ether 24 hrs.	0	5	4	7	7
				48	4	6+	7	7
4	Feb. 24	Ben Hur	0.5 cc. Ether 20 hrs.	0	4	3+	6+	6
				48	3	6	6	7
5	Feb. 24	Woodmanse	0.5 cc. Ether 24 hrs.	0	4+	5	7	7
				48	3	4	6	7
6	Mar. 13	Nixonite	0.25 cc. Ether 24 hrs.	0	3+	3+	7	7
				28	3	4+	7	7
7	Mar. 2	Ben Hur	0.5 cc. Ether 24 hrs.	15	3+	3−	7	7
				96	5	7	6+	.
				200	3+	4+	7	6−
8	Mar. 2	King David	0.5 cc. Ether 24 hrs.	15	3+	2	6	4
				96	4	3−	6	5
				200	3+	4+	7	6−

The influence of the intensity of a treatment on the enzyme activity of the twigs is shown in Table 9. The data indicate that in most cases a weak dose increases the fermentative action while a stronger dose has no influence or even causes a diminished activity. Unfortunately, most of these experiments were carried out late in the season.

It is very probable that during the early part of the season a strong dose might have increased the enzyme work when a weaker dose would have had no effect. This table shows very nicely how different varieties of apples behave in respect to their enzyme activity under similar treatment.

Another factor which influences enzyme activity is the intervals after treatment as shown in Table 10. In most cases the treated material showed a greater activity after an interval than it did immediately after treatment. (Cf. 1, 2, 3, 4, 5, 8, Table 10.) In some cases an interval may bring about less enzyme activity than immediately after treatment, even tho the ferments are still more active than those in untreated twigs. The interval seems to be unfavorable for the enzyme activity of the untreated material. (Cf. 1, 3, 4, 5, 6, Table 10.) In a few cases a rather long interval seemed to bring about an increase in the fermentative activity, tho an excessively long interval again diminished the rapidity of the enzyme action of untreated material. (Cf. 7 and 8, Table 10.)

Table 11 is inserted in order to show how the enzyme activity of different tissues of *Pyrus Malus*, Linn. vary with and without treatment. "Cortex," as previously explained, refers to all soft parts of the twig including lateral and terminal buds. "Twigs minus cortex" is what remains after removing the soft parts. The other terms used in the table are self-explanatory.

As might be expected the different tissues vary as far as their enzyme activity is concerned. The older cortex was least active at the latter part of the season. (Cf. 1, Table 11.) The same tissues were tested for their enzyme activity during October. Unfortunately at that time the plan of recording the enzyme activity had not yet been adopted and therefore the results are not included in the table. The observations noted were as follows: "Untreated material showed a little more action than etherized; bud material showed least; 1 year cortex medium; older cortex most enzyme activity." This is the reverse of what was obtained in the late season.

The reasons for choosing the cortex for most of the enzyme determinations have been mentioned. Table 11 gives experimental evidence which indicates that the one-year cortex is somewhat more active than the older cortex, the entire twig, or the hard woody parts of the twig.

2. Proteolytic Enzymes. A few experiments were carried out to determine the effect of rest period breaking agents upon proteolytic ferments of twig tissue. The methods used were very crude. The results obtained, however, are of sufficient interest to be included in

TABLE 11—DIASTATIC ENZYME ACTIVITY OF DIFFERENT TISSUES OF PYRUS MALUS TREATED VS. UNTREATED

No.	Date	Variety and Treatment	Inter-val Hrs.	Tissue	Enzyme activity			
					2 hrs.		4 hrs.	
					Untr.	Tr.	Untr.	Tr.
1	Mar. 12	Jonathan	0	Buds on spurs	4	6	7	7
		0.5 cc. Ether 24 hrs.		Cortex of 4 yr. twigs	2	2	5	5
				Cortex of 1 yr. twigs.	5	4	7	7
2	Mar. 12	King David	16	Entire twigs 1 yr. old	3−	2	6	5
		0.5 cc. Ether 24 hrs.		Twig minus cortex	2+	2	4	3
				Cortex 1 yr. old	3+	4	6	7
3	Nov. 24	Ben Davis	24	Buds	2+	3	3	4
		0.5 cc. Ether 24 hrs.		Cortex of young twigs	2−	2	2+	3

this discussion, but it should be borne in mind that only a few determinations were made.

These experiments were carried out as follows: A gelatin solution was prepared by adding 20 gr. pure gelatin to 100 cc. lukewarm water. Each of a number of similar vials received 25 cc. of this solution. After the gelatin had hardened, a set of material for the experiment was prepared as follows: In one vial was placed 5 gr. of treated apple cortex; in another, 5 gr. of untreated cortex; in another, 5 gr. treated cortex that had been heated to 100° C., and in still another, 5 gr. untreated cortex which had been heated to 100° C. Next, 25 cc. of pure water—sufficient to cover the cortex material— was added to each vial. Also the same quantity of water was added to other vials which contained gelatin but no cortex material. Toluene was added in all cases to prevent bacterial activity. The series was run in duplicate. The material was allowed to act for twenty-four hours at 20° C.

The amount of solidified gelatin remaining at the end of the period was used as an index to the proteolytic enzyme activity.[1]

The results of the test showed very clearly that the ether treatment increased the proteolytic enzyme activity as the least amount of the solid gelatin remained in the vials which contained the unheated cortex from etherized twigs. Very little of the gelatin had liquified in the vials containing water but no cortex.

The experiments were varied by allowing the cortex material to act on one cm. cubes of gelatin. Again the etherized material showed most action.

3. **Fat Splitting Ferments.** A series of experiments were carried out to determine whether the fat splitting enzymes of the twig tissue were influenced by agents which break the rest period. The results of these tests are not given as being conclusive since too few experiments were made.

The material used for these determinations was cortex from apple and ash twigs. A series of vials were prepared in duplicate as follows:

1*a* and 1*b*. 5 gr. cortex from etherized twigs plus 25 cc. castor oil emulsion.

2*a* and 2*b*. 5 gr. cortex from untreated twigs plus 25 cc. castor oil emulsion.

3*a* and 3*b*. 5 gr. heated cortex from etherized twigs plus 25 cc. castor oil emulsion.

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[1] Fermi, C. On the Presence of Enzymes. Centbl. Bakt. 2 Abt. 26. (1910) pp. 330-334.

4*a* and 4*b*. 5 gr. heated cortex from untreated twigs plus castor oil emulsion.

5*a* and 5*b*. 25 cc. castor oil emulsion only.

One cc. of toluene was added to all vials. The material was allowed to act at 35° C. for from ten to twenty-four hours. At intervals, some of the liquid in each vial was removed and tested for acidity by adding neutral litmus. In other cases, a few drops of phenolthaline were added to some of the liquid from each vial and then, drop by drop, weak NaOH was also added until the red color appeared. The material requiring the largest amount of NaOH, i. e., that which produced most acid, was considered to be most active so far as fat splitting enzymes were concerned.

In all cases tried, the etherized material was most active in producing fatty acids. The ash material was more active than the apple.

4. Oxidising Enzymes. The work of the oxidising enzymes as influenced by the rest period breaking agents was observed thruout the season. The CO_2 determinations, to a large extent at least, express the activity of the oxidases. However, the work of these ferments can be detected in other relatively simple ways. The browning of the exposed flesh of apples is familiar to all. This browning is due to an oxidase (maloxidase). Similarly Kastle[1] has demonstrated that the browning of freshly cut vegetable tissue which is exposed to air, is due to oxidases. The following experiment shows more specifically what may be expected in case of cortex material, and it also demonstrates the reliability of using this color change as a basis for judging the activity of oxidizing enzymes.

On February 8, 1914, some Wolf River apple twigs were collected. The cortex was scraped from these twigs and ground up finely. After mixing this material, a number of duplicate 5 gr. samples were weighed out, and treated in the following manner:

(A) Two lots in the open air without further treatment.

(B) Two lots in an atmosphere of ether. (1cc. per L.).

(C) Two lots heated to 100° C., then placed in open air.

(D) Two lots heated to 100° C., then placed in ether atmosphere.

At the end of one hour, all lots were removed to the open air. Lots *A* were somewhat brown. Lots *B* were very dark brown. Lots *C* and *D* were a similar green, showing no change in color.

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[1] Kastle, J. H. The Oxidases. Bull. 59, Hyg. Lab., U. S. Pub. Health & Mar. Hosp. Serv. Wash.

From this it must be concluded that the brown color was produced by a reaction in the tissue. Heating prevents the production of the color, and etherization favors it in unheated material. So far as known, the oxidising ferments are the responsible agents.

In determining how the agents used to break the rest period influenced the oxidases, the cortex was scraped from the treated twigs, ground up and exposed to the air for a short time. The color changes were then noted.

It is difficult to express quantitatively and accurately the variations in the shades of brown which were observed. Hence the results of these observations are not given in tabular form. Careful notes were made in all cases, and these are summarized in the following paragraphs.

In general, the treated material was not much deeper in color, than untreated material in the early part of the dormant period. Somewhat later the color differences were very striking, the treated cortex being the deeper brown in practically every case. Toward the close of the season the differences again became less noticeable, and in the last few weeks differences could seldom be observed. At this time of the year (March) the untreated material showed a much darker brown in a given period of time than at the beginning of the dormant season. In all cases where the material had been heated to 100° C. for a short time, it remained greenish for more than twenty-four hours. The brown color of unheated cortex appeared soon after grinding. The deeper the color, the sooner it appeared on the mass of tissue exposed to air.

The ground ash cortex did not become brown either with or without treatment. Different varieties of the apple showed variations in their behavior as far as coloration of the treated and untreated tissue was concerned. For example, material from the Woodmanse was usually somewhat lighter in color than Ben Hur; and King David generally gave the darkest coloration. Just what caused these variations is not definitely known. Cortex from weak twigs usually remained green for a longer time than cortex from vigorous twigs taken from the same tree. Cortex from similar twigs taken from similar trees of the same variety, showed about the same shade of brown when the same treatments were given.

The character and kind of treatment used affected the coloration to some extent, e.g., injured material became deeper brown than dry material. The cortex from twigs bathed in alcohol remained a deeper green than etherized material. In general the more intense the treatment, if not too intense, the deeper the brown color of the cortex, and the quicker it was attained after the latter was ground up. In a few cases, severe treatments very late in the season failed to result in the formation of the brown color, i.e., the untreated material was a darker brown than the treated.

Results, similar to those just given, were obtained by allowing the cortex material to oxidize the fresh colorless pyrogallol solutions to purpurgallic acid which is a deep cherry red.[1] The methods used and the nature of the results obtained may be illustrated by the following example: After preliminary treatment of the twigs, the cortex was scraped from the wood and ground up. Five grams were added to each of several vials. Some vials received heated cortex, while others received no cortex at all. To each of these vials, 50 cc. of 0.5 per cent freshly prepared pyrogallic acid were added. All were then placed in an oven at 35° C. Observations were made after a few hours. In a specific case the preliminary treatments were, 0.5 cc. and 0.25 cc. ether and check. The notes obtained after the cortex material had acted on the pyrogallic acid solution for two hours follow: "In all cases the cortex has settled, leaving the clear liquid above. In every vial, except the one with no cortex, this liquid has separated into two distinct layers, the lower one being yellow, while the upper is reddish brown. In the vials with the untreated material, the upper brown zone is not quite so broad as the lower; in the 0.25 cc. ether vial, the upper layer is about twice as broad as the lower; and in the 0.5 cc. ether vial, the upper layer is three times as wide as the lower. The yellow layer is the same shade in all cases. The upper layer grows darker as it becomes broader, being lightest in the untreated and darkest in the 0.5 cc. ether mixture. After ten hours all vials were uniformly colored. The yellow layer disappeared entirely and the liquid was very opaque.

This method of determining the oxidizing activity of the twig tissue is probably a little more quantitative than the one given previously.

In this connection it might be mentioned that treatments which caused the cortex to become deeper brown than that of untreated material, usually caused an earlier growth of the buds. When the difference in color between treated and untreated cortex was slight or not noticeable at all, the treated buds opened just about the same time as untreated. In those cases where the cortex from treated material did not become as brown as non-treated cortex, the untreated opened before the treated.

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[1] Kastle and Shodd. Phenolphthalein as a Reagent for Oxidizing Ferments Amer. Chem. Journ. (1901) 26. pp. 526-539.

C. SUGAR CONTENT OF TREATED AND UNTREATED TWIGS

In the foregoing experiments the enzymes found in treated twig tissue proved to be more active than in untreated twigs when allowed to act on foreign material.

When the tissue is ground up as was done in the preceeding experiments, some of the cells are ruptured and as a result their organization is disturbed. It is possible that ferments might show a different behavior after being freed, than under normal protoplasmic control.[1] How do the enzymes respond to treatments given the tissue, when they are allowed to act under protoplasmic control in living tissue? In other words, how do they affect the insoluble stored foods, especially starch, which are naturally found in the tissue? To answer these questions was the main object of the following experiments.

The material used, the manner of collecting the twigs and dividing them into similar groups, as well as the preliminary treatments given, were the same as in the foregoing experiments.

After the twigs had received the preliminary treatments, i. e., the application of the rest period breaking agent, they were ground up in the food chopper. The entire twigs were used. Duplicate 10-gram samples of treated and of untreated material were weighed out. These were then placed in coarse filter papers. Each sample was leached with 100 cc. of cold water. The water was poured over the material as quickly as possible so that the entire 100 cc. was added before any water came thru the filter.

The extract passed thru the filter very rapidly so that whatever material came thru must have been very soluble. In some cases a second and a third 100 cc. of extract were obtained from the same material, each 100 cc. being kept separate. The presence and amount of sugar in the extract was determined by means of Fehling's solution which was prepared according to the Official Methods of Agricultural Chemists (U. S. Department of Agriculture). Equal quantities of Fehling's, usually 1 or 2 cc., were added to equal quantities of extract, usually 5 or 10 cc. These mixtures were boiled for at least two minutes after which they were allowed to cool. All determinations were made in duplicate. The color of the supernatent liquid after the precipitate had settled was used as a basis for estimating the relative amounts of sugar present. A yellow liquid indicated that there was more sugar present than was required to reduce the Fehling's solution; a bluish color showed that the sugar which was present was insufficient to reduce the Fehling. The following simple experiment illustrates what has just been said.

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[1] Palladin, W. On Respiratory Enzymes. Jahrb. f. wiss. Bot. 47, pp. 431-461.

————————, Die Arbeit der Atmungsenzyme der Pflanzen unter verschiedenen Verhältnissen. Ztschr. f. Physiol. Chems. 47 (1906) pp. 406-451.

————————, Bildung der verschiedenen Atmungsenzyme in Abhangigkeit von dem Entwickelungsstadium der Pflanzen. Ber. d. d. Bot. Ges. 24 (1906) pp. 97-107.

Several 5 cc. samples of an apple twig extract were taken as follows: (1) Before dilution; (2) after diluting to twice its volume; (3) to four times its volume; and (4) to eight times its volume. To each of these samples 1 cc. of Fehling's was added. They were then heated for several minutes. After cooling and settling, the liquid in (1) was yellowish; in (2) a yellowish green; in (3) a bluish green; and in (4) blue. The amount of precipitate was greatest in (1) and least in (4).

The color of the fresh extracts was another basis for estimating the relative amounts of sugar contained in them. The apple twig extract was generally light yellow to deep orange. By diluting the deeper colored extract from two to twelve times with water, the light color was obtained. Before dilution the deeper colored extract showed more sugar than the light colored; after dilution, they contained equal quatities of sugar.

The results of these sugar tests substantiate those obtained with the enzyme tests. The following determinations are typical, and show the nature of the results.

1. Jonathan apple twigs were collected September 23, 1913. Some were etherized and some remained untreated. Sugar determinations were made twenty-four hours after treatment. The same experiment was repeated on October 28, and again January 12, 1914. In the first case there was no noticeable difference in the amount of readily soluble sugar of etherized and untreated twigs. A month later, the treated twigs had more sugar than untreated ones. In the last determination, both sets of twigs again showed similar amounts of sugar.

2. On December 7, 1913, one lot of Jonathan apple twigs were immersed in 10 per cent alcohol for fifteen hours; a second lot was dried at 35° C., fifteen hours; a third etherized twenty-four hours and a fourth remained untreated. After twenty-four hours the treated twigs showed the greater amount of sugar. On February 12, 1914, the same treatments were again applied to Jonathan twigs. In this case the untreated twigs showed as much sugar as the treated.

3. King David apple twigs were collected on February 8, 1914. One lot was etherized for twenty-four hours, another bathed in 10

per cent alcohol fifteen hours, a third in 0.5 per cent hydrochloric acid for fifteen hours, and a fourth reserved for a check. The untreated material contained the most sugar; the etherized and the HCl-bathed twigs, a lesser amount, while the twigs bathed in alcohol showed the least.

4. On November 8, 1913, Payne's Keeper apple twigs were collected. One lot was injured by beating the internodes with a knife handle, the other remained untreated. After twenty-four hours, the injured twigs contained the more sugar. When the same experiment was repeated on March 9, 1914, the untreated material contained the more sugar.

5. The twigs of mulberry, oak and ash in addition to those of apple were also used in these sugar determinations. The results obtained varied, with the species and varieties of a given species as well as the nature of the agent.

A number of other experiments might be cited, all of which indicate that treatments such as etherization, warm water bath, alcohol bath, hydrochloric acid bath, drying, mechanical injury, etc., when applied during early winter, increase the amount of readily soluble reducing sugars within twenty-four hours after the applications are given. If the treatments are given somewhat later in the season, the agents have little or no effect on increasing the amount of sugar. If delayed until very late, the untreated twigs will actually have more soluble sugar than similar treated material. While a given strong treatment applied late in the season may inhibit the formation of soluble material a less intense application made at the same time might actually cause the production of more sugar than in case of untreated material.

D. MISCELLANEOUS EXPERIMENTS AND OBSERVATIONS

A number of experiments and observations were made which do not fall in any of the previous classes. Those bearing on the main problems follow.

1. **Does Ether Have a Desiccating Influence?** As previously mentioned some experimenters believed all treatments given to break the rest period, especially etherization, have a desiccating effect. The term "desiccation," as used in this report, has reference to the loss of water from the tissue as evidenced by loss in weight. The term may also be used to designate the passage of water from the cells to the intercellular spaces as when ice is formed. In this

case, the tissue does not necessarily lose weight since the water remains within the twig.[1]

A dose of ether resulting in breaking the rest period has practically no desiccating effect on the tissue as may be seen from the data in Table 12. These data are typical. The figures show no difference in loss of moisture from treated and untreated twigs. When a very strong dose of ether was used, beads of liquid sometimes exuded from the tissue. Such treatment, however, did not break the rest period but injured the twigs beyond recovery.

TABLE 12—WEIGHTS IN GRAMS OF ETHERIZED AND UNTREATED APPLE TWIGS

Variety	Untreated		0.25 cc. Ether		0.5 cc. Ether	
	Before*	After*	Before	After	Before	After
Red June	48.45	48.10	52.25	52.00	49.60	49.30
Payne's Late Keeper	41.20	40.95	43.50	43.00	40.50	40.35
Woodmanse	52.05	51.85	52.00	51.85	53.05	53.00

* The twigs were weighed when collected and again after the preliminary treatment, which lasted twenty-four hours.

2. Color Change in Etherized and Untreated Apple Twigs. On November 24, 1913, also on March 9, 1914, one-year-old Ben Davis apple twigs were collected. One lot of each collection was etherized for twenty-four hours. After an interval of five days in each experiment, all twigs were immersed in distilled water at a temperature of 35° C. The notes taken on the first experiment read as follows: "After six hours from the time twigs were placed in water the bud scales and the shoulder just below the buds of the etherized specimens are becoming yellowish; the internodes remain normal reddish brown. The untreated twigs are normal reddish brown thruout. After eighteen hours all etherized twigs are entirely yellow. All untreated twigs are normal reddish brown thruout. After three days the bud scales and the bud shoulders of the untreated twigs are becoming yellow. After five days the untreated twigs are entirely yellow, the color being similar to that shown by etherized twigs after eighteen hours."

In the last experiment the following observations were recorded: "After twenty-four hours the bud scales and bud shoulders of treated twigs show a yellowish color while the remaining parts of the twigs are reddish brown. The untreated twigs are normal in color. After two days the treated twigs are yellow thruout except for a few isolated areas in the internodes which show the reddish brown tint. These areas of normal color are confined to the internodes nearest the terminal buds. A few of the untreated twigs are beginning to turn yellow on the bud scales and bud shoulders. All internodes are reddish brown in color. After eight days about one-fourth of the surface of untreated twigs is still reddish brown in the internodes. All etherized twigs are yellow thruout. They have been so since the fourth day."

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[1] Chandler, W. H. Freezing of Plant Tissue. Research Bul. No. 8, Mo. Agr. Exp. Station (1914).

These experiments indicate that etherization tends to hasten changes which normally occur within the twig.

3. **Amount of Sugar and Growth.** Jonathan apple twigs were collected on February 8, 1914. Some were etherized twenty-four hours; some remained untreated. The twigs remained in the respiration chamber for three days after which some etherized and some untreated twigs were placed in the greenhouse in beakers containing 50 cc. water. The cuts on the bases of the twigs were renewed every day so they would take up water readily.

After four days, the buds on the etherized twigs began to unfold; those on the untreated twigs remained normal. Sugar determinations made at this time (using the methods previously described) showed that the etherizing did not increase the sugar content. After a few more days the buds of the untreated twigs opened and by the end of the fourteenth day the leaves had outgrown those on the etherized material. This time the sugar determinations indicated that the normal twigs had the larger amount of sugar. After another four or five days the leaf growth in all twigs ceased. Again the relative amounts of sugar in both treated and untreated twigs was determined, both sets showing similar amounts.

4. **Respiration and Growth.** Jonathan apple twigs were collected on February 9, 1914. Some lots were etherized for twenty-four hours; some remained untreated. After this preliminary treatment, all were put in the respiration chamber. During the first few days the etherized twigs gave off more CO_2 than untreated twigs. During this period, and on the second day, some of the treated and some untreated lots were removed from the respiration chamber and, after clipping off the bases of the twigs, they were placed in the greenhouse in beakers containing water. The twigs were allowed to grow for a period of four days after which they were immersed in a strong formalin solution, in order to stop further growth, and at the same time preserve the general appearance of the growth already made. After the fourth day, the CO_2 production of the etherized material had fallen below that of the untreated. (Cf. curve

V, Fig. 5). On the sixth day, i. e., during that period when untreated twigs were producing more CO_2 than treated, some lots were again removed from the respiration chambers and placed under conditions favorable for growth. After growing four days, these twigs were immersed in formalin as in the first case. The following observations were made: "The etherized twigs which were supplied with warmth and moisture and other conditions necessary for growth within a few days after treatment have made more growth during four days than similar etherized twigs which were not placed under favorable growing conditions until six days after being treated. The untreated twigs in the first case have made slightly less growth than those in the latter case." In other words, the respiratory activity of the tissue which may be determined while the twigs are apparently dormant, serves as an index to the relative amount of growth which would occur if the tissue had favorable conditions for growth.

5. **Fungi on Treated Twigs.** Whenever the cut surfaces of etherized twigs were left exposed in a damp basement room, *Aspergillus* and *Penicillium* grew abundantly on them. Under the same conditions the untreated twigs showed no infection by the molds except in a few cases during the close of the dormant season.

6. **Color Changes in Water Extract of Twigs.** Decided color changes were observed in the water extract of the twig material. The following case is typical.

King David apple twigs were collected March 18, 1914. Some were etherized and some remained untreated. Cold water extracts were then made of both lots using 100 cc. water to leach 10 gr. of twig material. A number of test tubes received 10 cc. each of the extract from treated twigs; others received 10 cc. of extract from untreated material. The subsequent treatments which were given, as well as the observations made, are recorded in Table 13.

TABLE 13—COLOR CHANGES OCCURRING IN WATER EXTRACT OF ETHERIZED AND UNTREATED KING DAVID APPLE TWIGS

Treatment of extract	Source of extract	Color of extract		
		At Outset	After 2 days	After 5 days
None..............	Untreated Etherized	Light yellow Dark yellow	Light yellow Dark yellow	Light yellow Very light yellow
10% toluene added	Untreated Etherized	Yellow Dark yellow	Yellow Dark yellow	Yellow Dark yellow
Heated to 100° C.	Untreated Etherized	Yellow Dark yellow	Yellow Dark yellow	Yellow Dark yellow

The heating prevented any color changes. The addition of toluene had a similar effect. Where no special treatments were given, the changes were quite marked, more so than the table indicates. The extract from the etherized material which had been the darkest colored in the beginning was the lightest after five days. The changes were apparently due to bacteria.

7. **Gas Formation on Twigs.** On February 27, 1914, some one-year-old Red June apple twigs were collected. Similar lots were immersed in pure water, and in 5, 10, and 20 per cent alcohol respectively. After fifteen hours the following observations were made: "The twigs in 5 per cent alcohol are entirely covered with small gas bubbles; the material in 10 per cent alcohol and that in pure water has fewer bubbles; that in the 20 per cent alcohol has only a very few, scattered here and there." Similar results were obtained at various times.

8. **Gas on Finely Ground Cortex Preparation.** Jonathan apple twigs were collected on December 3, 1913. Some were immersed in 10 per cent alcohol for fifteen hours, some were bathed in water during the same period. After two days the material was prepared for the diastatic enzyme test as previously described. The preparation from material which had been treated with alcohol became covered with foam after twelve hours; none appeared on the preparation from material which had been immersed in cold water.

9. **Effect of Etherizing Frozen Seeds.** During 1912-13, Wiggans[1] carried on some studies concerning the rest period of seeds. In one experiment he determined the effect of freezing and etherization of seeds which had been previously soaked in water for three hours. After treatment, the seeds were germinated between moist filters. At least 100 seeds were used in each case. The freezing temperature was a few degrees below 0° C. Etherization was carried out immediately after freezing. A somewhat weaker dose of ether was applied than in the experiments described in this paper. The results obtained in the germination tests are summarized in Table 14.

It is seen that the freezing of soaked seeds reduced the percentage of germination in all cases below that of seeds which were soaked but not frozen. But if the freezing was followed immediately by etherization, the reduction in the percentage of germination was not so marked. In other words, the ether treatment apparently hindered, or counteracted to some extent, the destructive processes which were initiated by freezing. (It should be mentioned that all seeds of a given variety were soaked at one time. One-third of the entire lot were allowed to germinate without further treatment, while the remaining two-thirds were frozen. Of these frozen seeds, one-half were allowed to germinate while the remainder were etherized before placing them under conditions suitable for germination).

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[1] Wiggans, C. C. Studies Regarding the Rest Period of Seeds. Thesis. University of Missouri, 1913.

TABLE 14—PERCENTAGE GERMINATION OF SEEDS OF DIFFERENT SPECIES TREATED IN VARIOUS WAYS

To	Treatment	Index to Species Treated									Average
		A	B	C	D	E	F	G	H	I	
1	In H_2O, 3 hrs.....	64	78	12	76	88	84	88	4	50	60
2	In H_2O, 3 hrs..... Frozen 24 hrs.....	30	50	8	0	40	18	44	14	18	24.6
3	In H_2O, 3 hrs..... Frozen 24 hrs..... Etherized 12 hrs..	40	40	18	2	54	54	90	24	26	38.6

A	*Zea Mays*, L.
B	*Phaseolus lunatus*, L.
C	*P. vulgaris*, L.
D	*Citrullus vulgaris*, Schrad.
E	*Cucurbito maxima, Duchesne.*
F	*Spinacea oleracea*, L.
G	*Raphanus sativus*, L.
H	*Hibiscus esculentus*, L.
I	*Allium cepa*, L.

Results similar to those given in the above table were obtained when seeds were allowed to soak for six instead of three hours. The experiments with seeds are of interest because they suggest a very interesting effect of etherization.

E. INFLUENCE OF VARIOUS AGENTS ON THE REST PERIOD OF PLANTS

In connection with each experiment which has been described in the foregoing pages, some treated and some untreated twigs were placed in beakers containing water and put in the greenhouse where they were allowed to grow. The time when the buds opened was noted in all cases.

The results in general were similar to those obtained by previous investigators. It was found that during the very early part of the dormant season, the rest period was not so easily broken as later on. Toward the close of the dormant season it was found difficult to get any marked acceleration of growth. Heavy dosage of a given agent which produced earlier growth in twigs during December or early January, was found to injure the twigs and buds if given later in the season. The specific behavior of some twigs has already been referred to in connection with some of the experiments.

A few observations might be of interest in this connection.

In some cases a very strong does of ether stimulated the terminal bud only, while a dose only half as strong caused the laterals as well as the terminals to grow earlier than untreated buds. In twigs which were frozen, the basal buds grew earlier than those nearer the tip. In many cases, a given dose of ether stimulated the leaf buds while the flower buds were killed by the treatment. In several cases mechanical injury just below or near a bud caused that bud to burst into growth while the buds above and below remained dormant. As a rule, desiccation produced the most uniform results, i. e., the drying caused all laterals as well as terminals to come out about the same time. Usually on untreated twigs the lateral buds came out very irregularly, some of them opening several days before others.

On January 16, 1914, a number of similar, vigorous, one-year-old King David apple twigs were collected. All were about 75 cm. long. Some were left entire; some were cut in half; while in other cases the terminal one-third was cut off. The lower cut surfaces of each lot of twigs were put in beakers of water and placed in the greenhouse. The photograph (Fig. 8) shows the general appearance of the twigs after one month. The twigs at A were those which were left entire. Very few terminal buds had opened. The laterals of the lower portions of the twigs had made a good growth. Most of the laterals farther up on the twig were dormant. The lower two-thirds of some of the twigs are shown at *B*. In this case the buds nearest the injured surface made a very vigorous growth. The remaining lateral buds also made more or less growth. The twigs at *C* were the upper parts of those shown in *B*. The terminal portions made no lateral growth. The terminal buds, however, were beginning to grow somewhat more vigorously than those at *A* or *D*. The upper halves of those twigs which were cut into two equal parts, are shown at *D*. In these, the terminals made some growth. Some of the lateral buds began growing rather vigorously but many of them made only a feeble growth.

The behavior of these twigs indicates that the water supply which reached the buds was one of the important factors in their development. It should be mentioned that the buds in all cases were fully turgid.

On January 22, 1914, a number of very vigorous one-year-old twigs were collected from a Jonathan apple tree. Some very weak twigs were also selected from the same tree. The former were more than one meter long, while the latter were only about 15 to 20 cm. in length. These twigs were placed in beakers containing water and they were allowed to grow in the greenhouse. The photograph (Fig. 9) shows the growth made by each set after one month. It is seen that the terminal buds of the vigorous twigs (A) made much more growth than the weak twigs (B). The former opened within a few days after they were brought into the greenhouse; the latter first burst after two weeks.

Did the tall twigs finish their rest before the weak twigs? Did they have a rest period at all, or did they stop growth because they were forced to do so by the cold weather? The terminal buds were not as well protected by their natural coverings as the weaker twigs. Apparently growth in the strong twigs stopped rather suddenly so that no time was left to finish out the buds as in the case of weaker twigs.

NEW METHODS FOR BREAKING THE REST PERIOD

A few new methods of forcing growth in dormant twigs were employed with more or less success but in no case was any attempt made to determine the exact dose to produce the most effective results. However, there is little doubt that for each treatment there is an optimum dosage which will vary with the species, the season and perhaps with other factors. The main object of these tests was to determine if the treatments given would actually stimulate growth. Relatively little attention was given to the degree of stimulation.

Treating apple twigs by immersion in solutions of 0.25, 0.125, .0625 and .03125 per cent $CuSO_4$ for twelve hours on December 7, 1913, produced earlier growth than untreated material. The stronger the concentration the better the results. The same treatment applied to *Forsythia* at the same time proved toxic to the buds.

Immersing in 0.5 per cent HCl for sixteen hours was effective in forcing apple buds as well as *Forsythia*. $CuSO_4$ treatments apparently were more effective than the HCl bath on the apple.

On December 17, 1913, *Fraxinus Ornus* twigs were immersed in 5 per cent, 1 per cent and 0.5 per cent oxalic acid for twelve hours after which they were placed in water in the greenhouse. After twenty-five days, the terminal buds of twigs treated with the one per cent and the 0.5 per cent solutions became active, while untreated twigs remained dormant. Acetic acid baths gave similar results. *Quercus coccinea* twigs did not respond to these treatments.

A number of different solutions were tried for their forcing qualities. Ash, oak, apple, plum, and maple twigs were used. The twigs were immersed in the solutions for twelve hours on January 20, 1914. Those treatments proving effective were: For ash, 5 per cent $NaNO_3$ and 5 per cent ammonium oxalate; for maple, 0.5 per cent KCl; for plum, 1 per cent ammonium oxalate, 0.5 per cent KCl, 5 per cent $NaNO_3$ and 0.5 per cent $CuSO_4$; for apple, 1 per cent and 0.5 per cent $CuSO_4$ and 1 per cent KCl.

Good results were obtained with MnO_2 treatments. On January 19, 1914, ash, apple and oak twigs were dipped in MnO_2 paste made of powdered MnO_2 and water. The paste adhered to the twigs and formed a slate colored coating when dry. These treated twigs, also normal ones, were placed in a greenhouse in water. Fig. 10 shows the results one month following treatment. The buds on the treated ash twigs had swollen very much compared with those on untreated ones. The former had also formed an abundance of callus tissue. The buds on treated oak twigs were much more active than those which received no treatment. Apparently, the apple does not respond to the MnO_2 treatment so late in the year. It should be mentioned that the MnO_2 might have influenced the twigs indirectly by absorbing heat due to its dark color.[1] The apple, however, is normally affected by heat, and the MnO_2 treatment was non-toxic since both check and treated buds began to grow at about the same time.

DISCUSSION OF RESULTS OF RESPIRATION EXPERIMENTS AND OTHER TESTS

Many of the results presented in this paper supply experimental proof in support of the theory of Klebs, viz., that after length growth has ceased in plants, the leaves remain green and active and continue to assimilate organic foods which accumulate in considerable quantities. The rest period breaking agents apparently do stimulate fermentative activity. In most cases when diastase enzymes are made more active, earlier growth is induced. However, this is not always the case. A striking example is found in the case of the ash. This species has a very high diastatic activity, yet it forces with much difficulty. The same was found to be true of several varieties of apples tho not to so great an extent. How can we account for these results?

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[1] Whitten, J. C. Winter Protection of the Peach. Bulletin No. 38, Missouri Agr. Exp. Sta.

By referring to the figures in Table 2, it is seen that etherization has very little effect in stimulating the CO_2 production of ash. It is further noted that the ash tissue oxidized very slowly. It has also been mentioned that some varieties of apples oxidize their tissue more readily than others. Those which oxidize most are most easily forced.

The respiration curves of the Jonathan apple likewise indicate that the increased amount of CO_2 produced as a result of treatments varies with the advance of the season. When the stimulation was greatest, the forcing of growth was most marked.

It is quite possible that a given resting tissue may contain sufficient soluble material to support growth as has been pointed out by Johannsen.[1] Treatments in such cases might produce still more sugar than was already present. However, the food must be usable to be of value to the plant. Before it can be used at all, energy must be made available. In order to furnish energy, material must be oxidized and the oxidizing enzymes are responsible for this oxidation process to a large extent. Again, not all food material is readily oxidized. Certain substances, e. g., starch, must first be changed to sugars before combustion occurs. In some plants, i. e., in those where sugar is normally abundant, a rest period breaking agent needs only to stimulate the oxidizing forces; while in others it becomes necessary to set in action those forces which convert insoluble food into readily oxidizable and therefore energy yielding material, as well as to stimulate the oxidizing agents themselves.

The question may arise "Do these agents affect the enzymes directly or, indirectly, by first influencing the general protoplasmic organization?" The more growth there is, the greater the enzyme activity, and hence it might be said that growth has already been started as a result of the stimulus given by the rest period breaking agent, and therefore enzyme activity naturally might be expected.

There is no reason to suppose that the rest period breaking agents single out and influence specific organisms of the protoplasm, such as the enzymes. Many other portions of the "protoplasmic makeup," a phrase which covers much that is unknown, might be affected at the same time. We simply have an easy method of determining the enzyme activity but have no sure way of knowing whether other parts of the protoplasm are not affected at the same time that the enzymes are. On the other hand, it is conceivable that such specific portions of the protoplasm as the enzymes could be affected directly by outside agencies. In other words in one case the treatment may directly affect the seat of protoplasmic activity—whatever that may be—which in turn influences all other parts; while in another case, the treatment may indirectly affect the protoplasm by first influencing some specific portion of its structure.

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[1] Johannsen, W. Das Aetherverfahren beim Frühtreiben, etc. (Zweite Anfl. Jena 1906).

The thought in the foregoing paragraph might be illustrated by considering the complex wheels and cogs and other parts of a clock as the protoplasmic structure. By winding the spring, energy is stored up thru which the complex mechanism is set in motion. This spring may be considered as the seat of protoplasmic activity which brings about the movement of all other parts of the clock. The rate at which this spring unwinds is determined by a pendulum. This part may be regulated so the clock goes fast or slow. In this case, we are affecting a specific portion of the mechanism directly, and as a result of that effect the entire structure is, in turn, made to respond.

All experiments seem to indicate that etherization and other means of breaking the rest period intensify and hasten the normal physiological processes. As a result, metabolic changes are carried out in a much shorter time than under ordinary conditions. This is shown especially and in a striking manner by the experiment in which treated and untreated twigs were kept under water. This phenomenon was exhibited by all the other experiments.

SUMMARY AND CONCLUSIONS

Summary. The existence of a rest period in plants has been definitely established, together with the fact that the normal rest in most plants may be shortened at will by certain treatments. There has been much speculation as to the cause of the rest period and particularly the specific effects of ether and other agents which produce growth in dormant plants.

Believing the beginning of the rest period, as well as the breaking of the rest, was in some manner associated with enzyme activity, a series of respiration experiments was begun in 1913 and carried on thru a part of the following year. It was known that anesthetics, mechanical injury, high temperatures and other agents stimulate the respiratory processes in both growing and dormant plants. The experiments conducted were for the purpose of securing information on the following points: To determine the effects of drying and freezing on CO_2 production of dormant apple twigs; also to determine the influence of the same dose of ether on CO_2 production in different species of dormant twigs; and to test the effects of the same dose of ether on CO_2 production of dormant apple twigs at different times during the season.

Special apparatus was designed for conducting the respiration tests. There were six chambers consisting of tall glass jars, each with a capacity of 2.5 liters. These contained the twigs to be tested. The jars were connected on one side with a KOH tube and on the other with a $CaCl_2$ tube and Geissler bulbs containing a saturated solution of KOH. The six jars were inclosed in a large double-walled galvanized iron chamber with water jacket. The air was drawn thru the tubes, jars and bulbs at the rate of three liters per hour. The KOH freed the ingoing air of all CO_2 and the outgoing air passing thru the $CaCl_2$ tube gave up all its moisture and the KOH in the Geissler bulbs absorbed the CO_2 given off by the twigs, while any moisture evaporating from the bulbs was retained by the $CaCl_2$ tube next to the aspirator bottle. A self-recording thermograph inside the large chamber registered between 15° and 18° C. thruout the tests.

A set of twigs was frozen at -15 to -19° C., another dried at a temperature of 26 to 31° C., and a third placed in a humidor at room temperature. After sixty hours all were placed in the respiration chambers. During the first day the froxen twigs produced four times as much CO_2 per hour, per 100 grams of twigs, and the dried twigs three times as much as the twigs that had been kept moist to check the results.

Dormant apple, ash, oak and mulberry twigs were exposed to ether used at the rate of one-half cc. per liter of space, for twenty-four hours. These with control twigs were then placed in respiration chambers. The normal respiration was found to be greatest in the mulberry, and least in apple and ash. Etherization caused increased CO_2 production in all cases, but it was greatest in the apple. When placed in the greenhouse those species in which CO_2 production was stimulated most by etherization began growing earlier than similar untreated twigs. Where the treatment failed to stimulate CO_2 production— as with oak and ash—the growth was not materially hastened.

Apple twigs were etherized in October, November, January, February and March. In all cases from the earliest to the latest date the respiration was markedly increased during the first three days. In October, November and January this increase continued after the third day while later in the season—in February and March —the respiration actually decreased very greatly (as compared with the control twigs) beginning with the fourth day after treatment.

In other words the later the date, and consequently the nearer the end of the resting phase, the shorter was the period during which respiration could be stimulated by the ether treatment. All twigs were placed in the greenhouse. As before, where stimulation of CO_2 had been most marked, growth took place the quickest.

It is known that enzymes soon become inactive if the products of their work are not utilized. Also it is a matter of common observation that the leaves of woody plants continue to elaborate food in autumn for some time after length growth has ceased, resulting, it is believed, in a great accumulation of carbohydrates, thus greatly hindering the work of the ferments and perhaps causing them to become wholly inactive. Believing that the secret of the setting in of the rest period, as well as the breaking of the rest by treatments, was to be found in a study of the workings of the enzymes in the tissues of dormant twigs, an investigation along this line was made. The experiments were as follows: (1) With diastatic activity; (2) presence and activity of proteolytic enzymes; (3) fat splitting ferments; and (4) oxidizing enzymes. The agents employed for breaking the rest period in the twigs used in these studies were etherization, desiccation, warm water bath, alcohol bath, hydrochloric acid bath, sodium nitrate spray and mechanical injury. After treatment the cortex was scraped from the twigs and ground into a fine pulp. The first test was for diastatic activity. Potato starch was mixed with a portion of the cortex pulp and two per cent toluene added to prevent bacterial growth. The material was incubated at a temperature of 35° C. The tests for evidences of the presence of diastase were dependent upon the well-known color activity of iodine upon starch. If a starch-changing ferment such as diastase acts upon starch for a time, the addition of iodine does not produce a pure blue color, but instead a blue-purple or violet, red-purple, red, red-brown, yellow-brown, or no color change at all. Since the color reaction indicates the degree to which starch has been changed, then the color obtained at the end of a definite time serves as a basis for determining the enzyme activity. Practically all of the determinations made in this experiment were in duplicate.

To make the results of the test comparable, seven easily recognized colors were taken as a standard. Quite arbitrarily it was considered that the ~~less intense or lighter~~ darker the color—the less the enzyme activity; conversely, the ~~more intense or darker~~ lighter the color—the more active the ferments.

The control material for the experiment consisted of a quantity of the cortex which had been heated in water to a temperature of

100° C. for a few minutes. This upon being allowed to act upon the starch paste showed no color reaction with the iodine. The tests showed that the agents which are known to break the rest period increased the diastatic enzyme activity of the dormant tissue.

The extent of the activity varied considerably, depending upon the species of dormant twigs used, the rest breaking agent employed, time of treatment, etc. In general the diastatic activity following treatment was found to agree very well with the extent to which the treatments broke the rest period, or produced early growth.

The test for the presence of active proteolytic enzymes in the tissue of dormant twigs was determined by finding to what extent such woody tissue, after being treated with rest period breaking agents, would liquify hard gelatin. The results of the test showed very clearly that the ether treatment caused a very great amount of proteolytic enzyme activity.

A few tests were made to determine whether the fat splitting enzymes were affected by agents which break the rest period. Cortex from treated material was allowed to act upon castor oil emulsion at 35° C. for from ten to twenty-four hours. At intervals the liquid was tested for acidity by using neutral litmus, or a few drops of phenolpthalein, and adding NaOH solution drop by drop until the red color appeared. In all cases tried, the etherized material was the most active in producing fatty acids.

Evidences of the activity of oxidizing enzymes as influenced by rest period breaking agents were frequently observed thruout the season during the progress of the respiration experiments. A special experiment with treated apple twig cortex in late winter showed that etherization of dormant plants may greatly arouse the activity of the oxidizing ferments. These tests were dependent upon color changes of tissue in the open air, after being exposed to treatments.

The sugar content of treated and untreated twigs was determined by testing water extract from the twig cortex with Fehling's solution, according to the Agricultural Chemists' official method. The results of the sugar test substantiated those obtained in connection with the enzyme activity, thus indicating that treatments such as etherization, warm water bath, alcohol bath, hydrochloric acid bath, drying, mechanical injury, etc., when applied during the early winter increase the amount of readily soluble reducing sugars within twenty-four hours after applications are made. If treatments are given somewhat later in the season, the agents have little or no effect on increasing the amount of sugar. If delayed until very late the untreated twigs will actually contain more soluble sugar than where treated.

Special efforts were made to determine whether ether exerts a desiccating influence upon woody tissue. It was found that a dose which results in breaking the rest period has practically no desiccating effect on the tissue, as the untreated twigs lost just as much moisture as the treated. There was very little moisture lost in any case. When very strong doses of ether were used, large beads of liquid sometimes exuded from the surface of the twigs. Such large doses, however, did not break the rest period but they did injure the twigs beyond recovery.

From time to time it was noticed that the bark of etherized twigs seemed to change color. Special treatments with ether showed that this treatment tends to hasten changes within the twig which would normally occur in untreated material much later on.

A correlation was noticed between the amount of sugar available in twigs and the early date at which they were enabled to begin growth. However, untreated twigs, while beginning growth much later than treated ones, often showed a tendency to catch up with and even to outsrtip the treated twigs in point of vigor and amount of growth made.

It was found by experiment and observation that the respiratory activity of the tissue of dormant twigs may serve as an index to the relative amount of growth which such twigs would make under favorable growing conditions.

It was noticed that species of fungi nearly always grew upon the cut surfaces of the etherized twigs, while untreated twigs in the same environment showed no infection by the molds except in a few instances just at the close of the dormant season.

It was often observed that etherized twigs, when placed in beakers to grow, seemed to discolor the water. Tests made for the purpose showed that something was dissolved from the twigs by the water, giving the latter different colors. It was found that heating the treated twigs to a sterilizing temperature and also the addition of toluene prevented the coloring of the water extract. The color changes were apparently due to bacteria.

Wiggans studied the effects of freezing and etherizing on germination of seeds. It was found that freezing soaked seeds reduced the percentage of germination in all cases below that of seeds which were soaked but not frozen. However, it was found if the freezing was followed immediately by etherization, that the reduction in the percentage of germination was not so marked. Apparently the ether treatment hindered or counteracted, to some extent, the destructive processes which were produced by freezing.

The influence of various agents in breaking the rest period of plants was studied in connection with all of the leading treatments and the results were similar to those obtained by other investigators It was found during the very early part of the dormant season the rest period was not so easily broken as later. Also toward the close of the dormant season it was difficult to induce any marked acceleration of growth. Heavy dosage of a given agent readily producing growth in twigs during December or early January, was found to injure the buds when treatments were made later in the season.

A few new methods for breaking the rest period were successful. These were immersion in weak solutions of copper sulphate, hydrochloric acid, oxalic acid, acetic acid, sodium nitrate, potassium chloride, and manganese dioxide.

Conclusions. The results of the respiration studies and other tests seem to justify the conclusion that the specific effect of all rest period breaking agents on dormant woody tissue is the stimulation of the enzymes. The experimental evidence submitted shows that diastatic, proteolytic, fat-splitting and oxidizing enzymes are induced to become active or, are stimulated into greater activity, by treating twigs with ether and other agents. The extent to which enzyme stimulation will result in quick growth in dormant plants will depend upon the species of plant, kind of treatment, dosage, stage of dormancy and other factors.

It now becomes possible to advance a theory as to the cause ot the beginning as well as the end of the rest period, in woody plants. In general it would seem that the rest sets in on account of the inhibition of enzyme activity due to over-accumulation of the products of their work. The early phases of the rest period occur and are passed thru while the plants are in full leaf and often while some of the parts are making active growth. The parts to enter the resting state first in fruit trees particularly, are the so-called spurs—short lateral out-growths—usually from wood that grew the previous year. These cease growing early in the season, the writer believes, on account of imperfect sap circulation in those parts. It is always the spurs that first stop growing. Withholding water from trees causes early dormancy in all the parts but the spurs are the first to form terminal buds. The crude sap from the roots rises most rapidly in those branches and twigs that are nearest in a straight line upwards from the ground. It would seem then, that the spurs on account of their position, are deprived of water supply very early in the growing season. Also assimilation takes place first or at least most rapidly, in those parts that first approach a state of maturity. With a decreased water supply and a greatly increased deposition or accumulation of carbohydrates, enzyme activity is soon checked if not almost entirely inhibited.

As the season advances, two factors act together to compel the main branches to cease making length growth and form terminal buds. One of these forces is the rapid accumulation of carbohydrates in branch after branch, and the other is the approach of cold weather. Here it may be objected that oak, apple, peach and similar trees growing in a warm greenhouse go dormant as usual. True, but growth continues much longer than on outside trees because only one force is being exerted to bring about a state of dormancy. In the mild climate of Central California and even in sub-tropical regions as far southward as deciduous trees occur, the latter behave as tho they were growing under glass.

Deciduous trees perhaps enter their most profound state of rest at about the time the leaves fall or, under glass, at the time when all terminal buds have formed. That the main dormant period happens to be coincident with the winter season is doubtless a mere coincidence as the winter *per se* may, and probably does, have nothing to do with the beginning of the rest. In the somewhat limited observations of the writer in sub-tropical parts of America and the Mediterranean countries, away from the disturbing factor of frost occurrence, deciduous plants were found to conform in the main to the principles of growth and dormancy as mentioned above. Indeed, the same principles of growth and dormancy may be extended to cover deciduous plants in the tropics, where, we are told by responsible observers, there may be several periods of growth and repose, the cessation of growth always being followed by leaf-fall.

During the period of the main or middle rest of trees all activity does not cease by any means. The enzymes doubtless continue to work and some of the products of their activity are utilized in the processes of respiration. In this way the excess supply of carbohydrates may be reduced. This is perhaps the explanation for the removal of the so-called "hindrance" to growth in dormant plants by means of treatments which break the rest period. The treatments in such cases merely hasten the processes—perfectly normal in themselves—which would take place later if the enzymes were allowed to act in a natural manner.

The rest period of plants does not end suddenly. On the contrary, under natural conditions it ends very slowly. The transition stage between the main, deep state of rest and the first beginning of growth has been aptly termed the "after rest." During this period there appears to be considerable enzyme activity. Also at this time rest breaking treatments have little or no effect in hastening growth. Indeed, treatments which, during the middle rest, were capable of starting growth in a short time, now often injure the plants and actually hinder growth. Just as in the beginning of the rest period, certain of the plant parts end their rest before other parts. The enzymic activity in one twig may be more rapid than in another but as soon as the excess supply of the products of their work is reduced to a certain point, growth begins. When this equilibrium has been established or is about to be reached, treatments not only fail to hasten but may even retard the starting of growth.

Briefly then the rest period first begins to set in on account of the inhibition of the enzymes by the accumulation of the products of their work. This is the early rest of mid or late summer. In the fall, excess supplies of carbohydrates continue to be accumulated and the further inhibition of the enzymes is actively aided by the approach of cool weather. These factors acting together bring about the main or middle state of rest. However, since dormant trees are never completely at rest—respiration continuing all the time, and doubtless enzyme activity too—the over-accumulation of carbohydrates is gradually reduced. Toward the last of this period occurs the after-rest which, as the enzymes become more and more active, gives place to the beginning of growth.

The length of the rest (the total time occupied by the three rest phases mentioned), varies greatly with the different species. In some the rest lasts from June or July to March or April, while others may be ready to grow again after two or three weeks of dormancy.

ACKNOWLEDGMENT

Too much credit cannot be given to A. J. Heinicke, research scholar in horticulture, 1913-14, but now instructor in pomological research in Cornell University, for valuable services rendered in connection with this investigation. Mr. Heinicke displayed great originality in devising apparatus and methods for conducting the various tests described in this bulletin. A great many of the tests were very tedious and exacting, and required great devotion to the work in order that they might be carried out in detail. Furthermore, it should be added that Mr. Heinicke conducted the tests and recorded his observations with care and accuracy. In recognition

of the above-mentioned services, the writer of this report hereby extends to Mr. Heinicke his grateful acknowledgment for the valuable work done in making this report possible.

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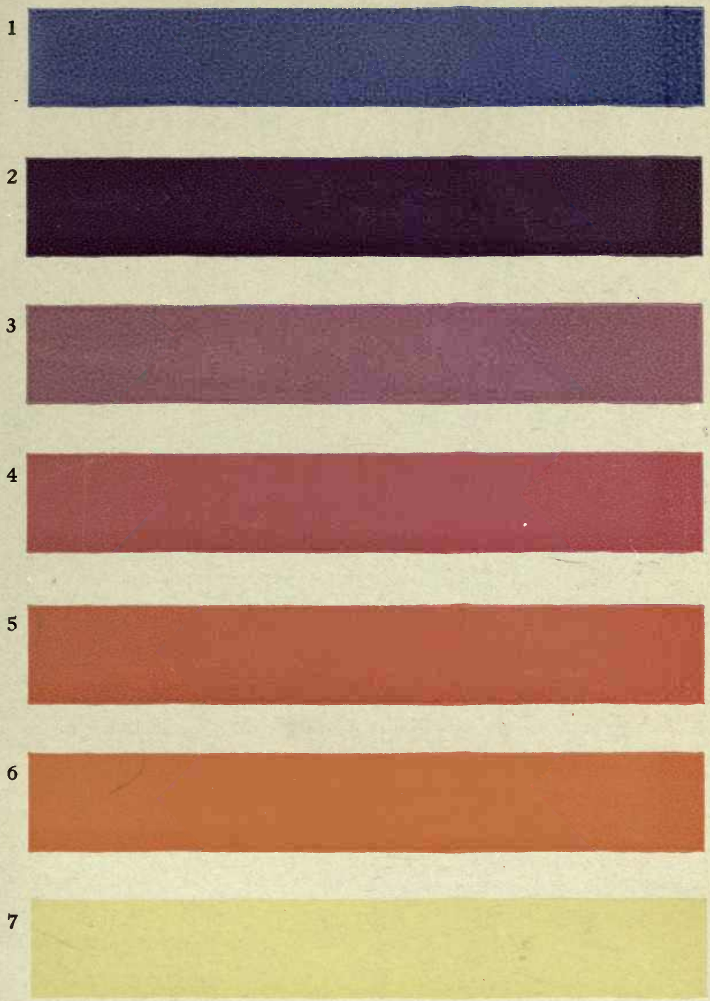

Fig. 7. *Colors obtained with iodine and starch-dextrose. These colors were used as a basis for measuring the diastatic enzyme activity as influenced by treatments given to break the rest period. For convenience the colors are numbered from 1 to 7. The deeper blue the color reaction the less the enzyme activity as no starch has been converted, hence the smaller the number, the less the enzyme activity; the greater the number, the more active the ferments.*

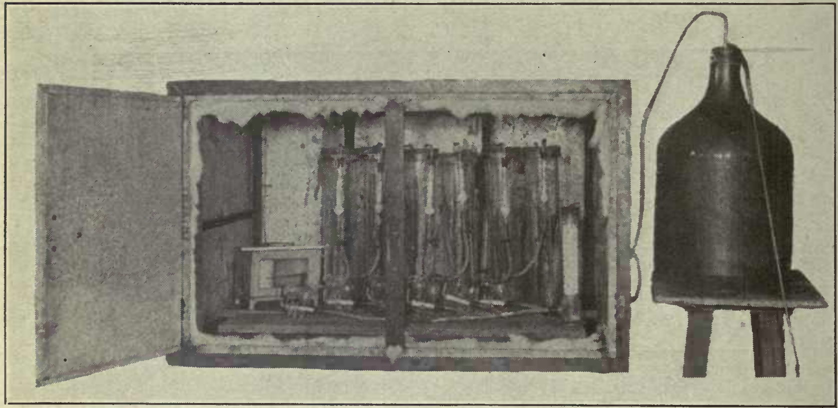

Fig. 1. *Respiration apparatus. Six glass cylinders with Geissler bulbs and KOH and* $CaCl_2$ *tubes attached, enclosed in double-walled chamber with water jacket.*

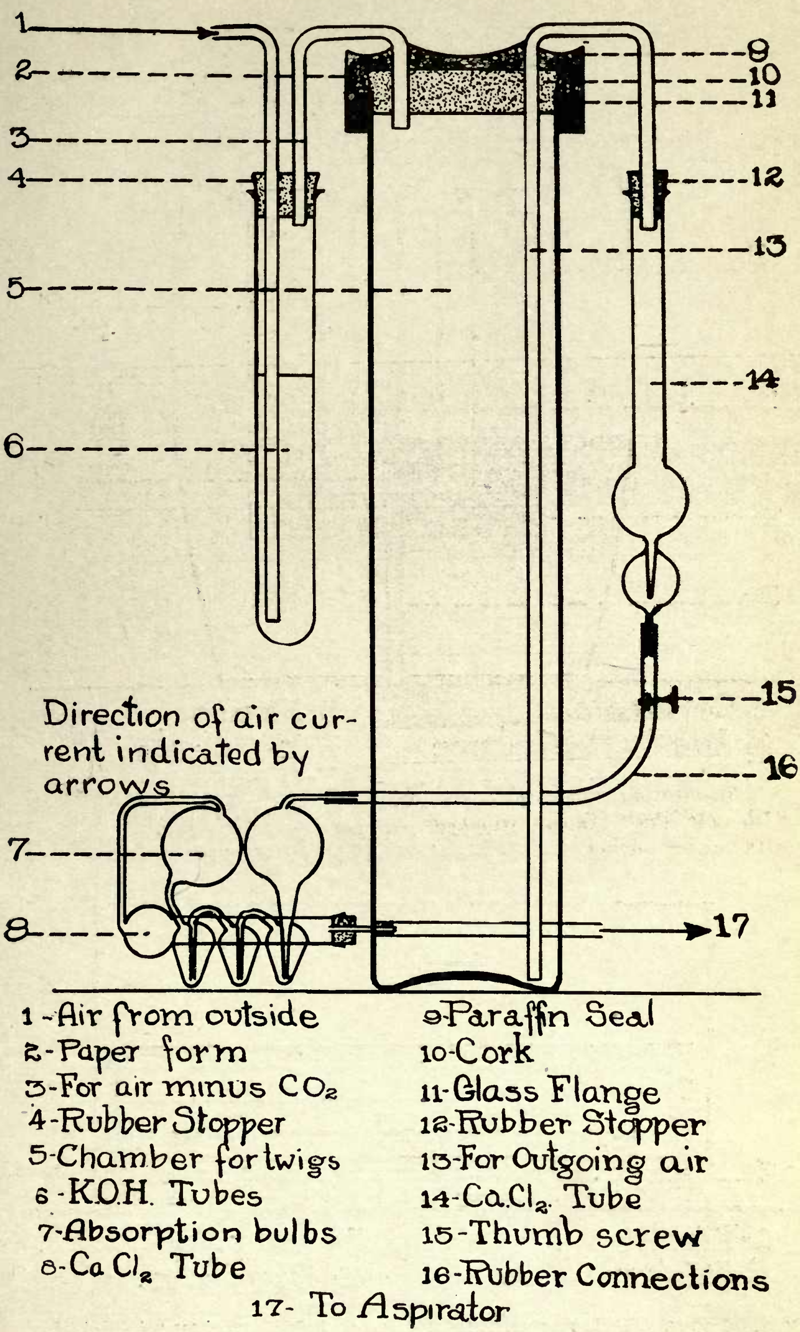

Fig. 2. *Respiration chamber x one-fourth shown in detail.*

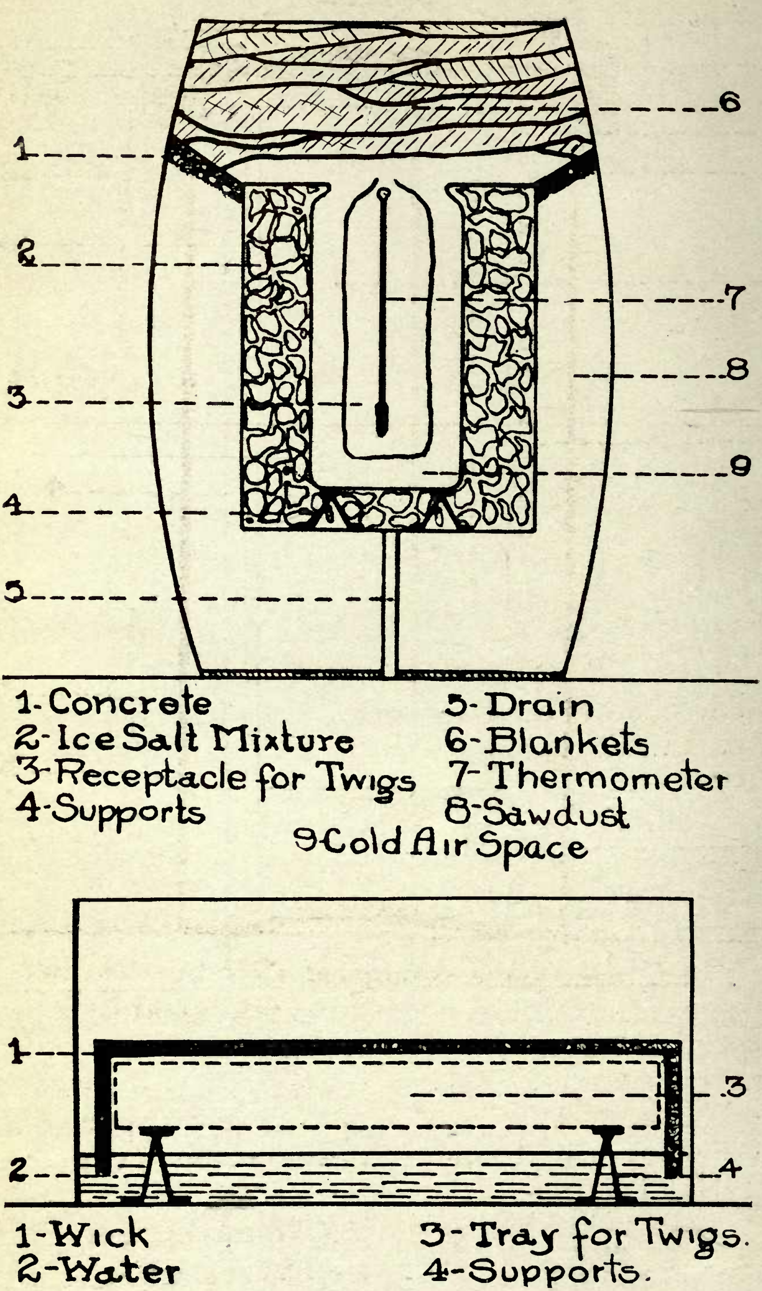

Fig. 3. *Upper, freezing apparatus and lower humidor, shown in detail.*

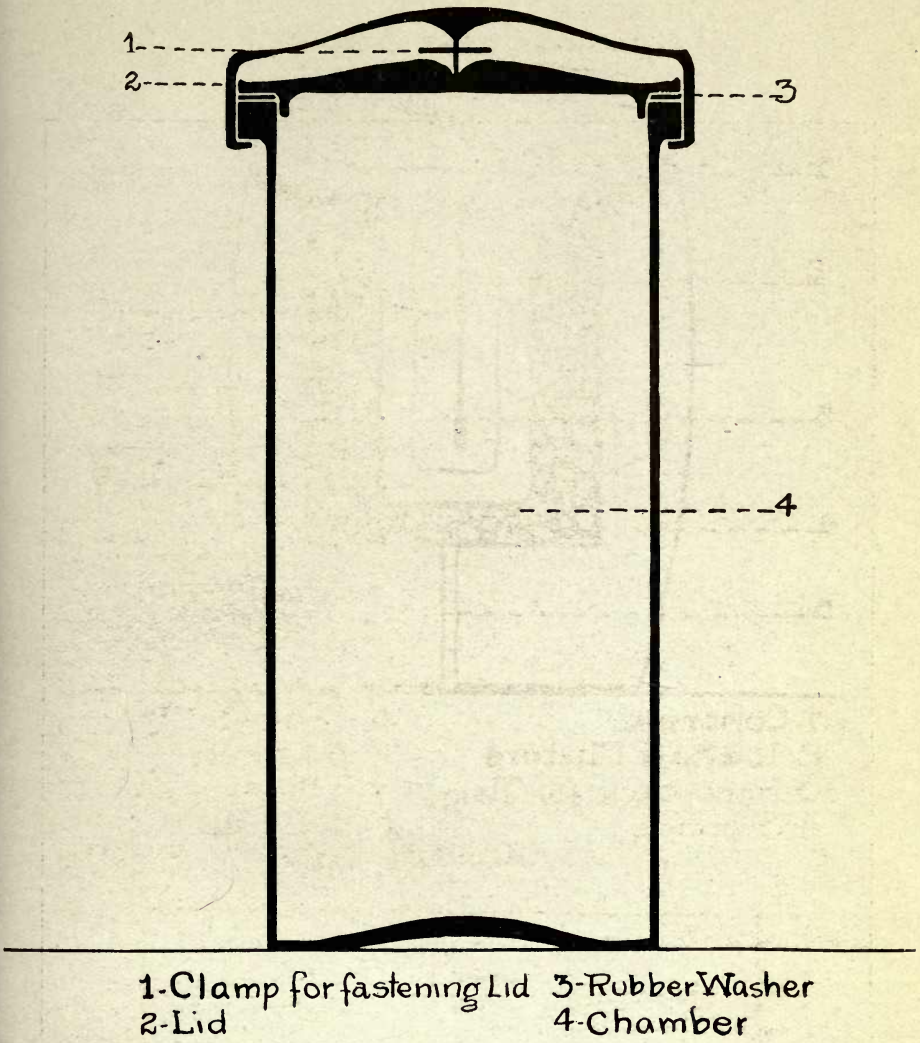

Fig. 4. *Etherizing chamber x one-fourth.*

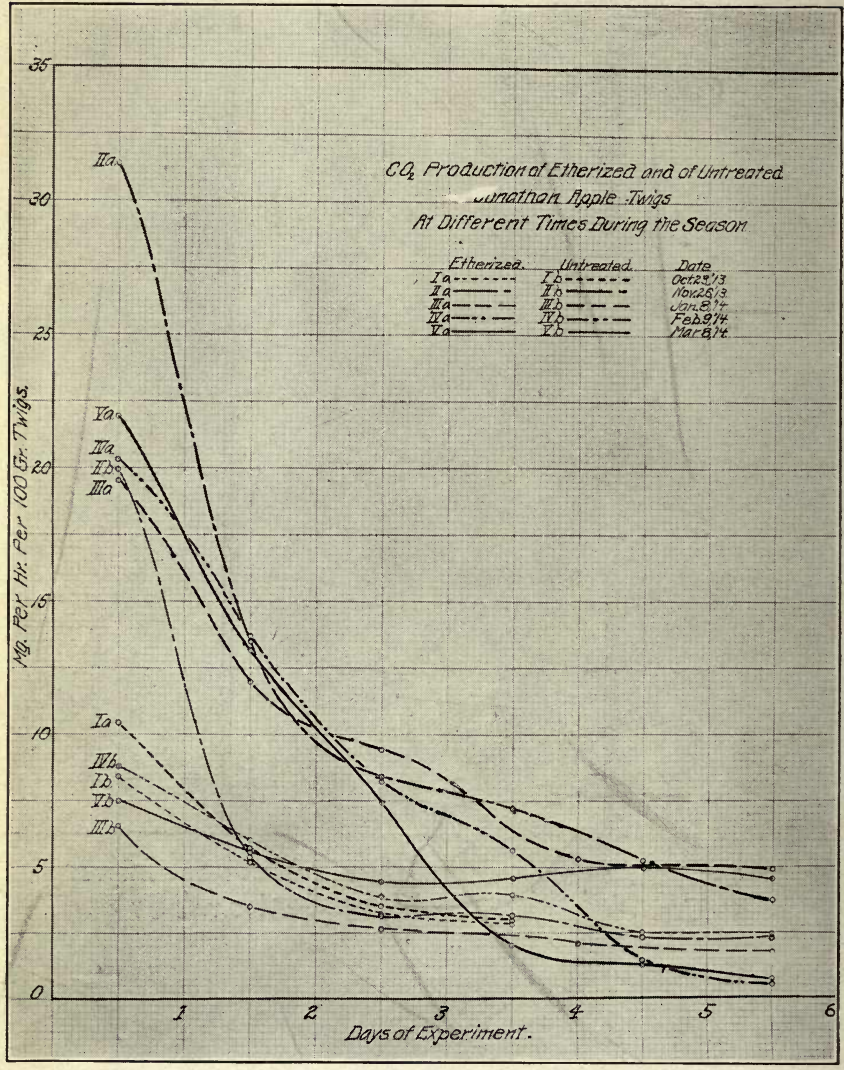

Fig. 5. *Graphs showing production of CO_2 by etherized and untreated Jonathan apple twigs at different times during the season.*

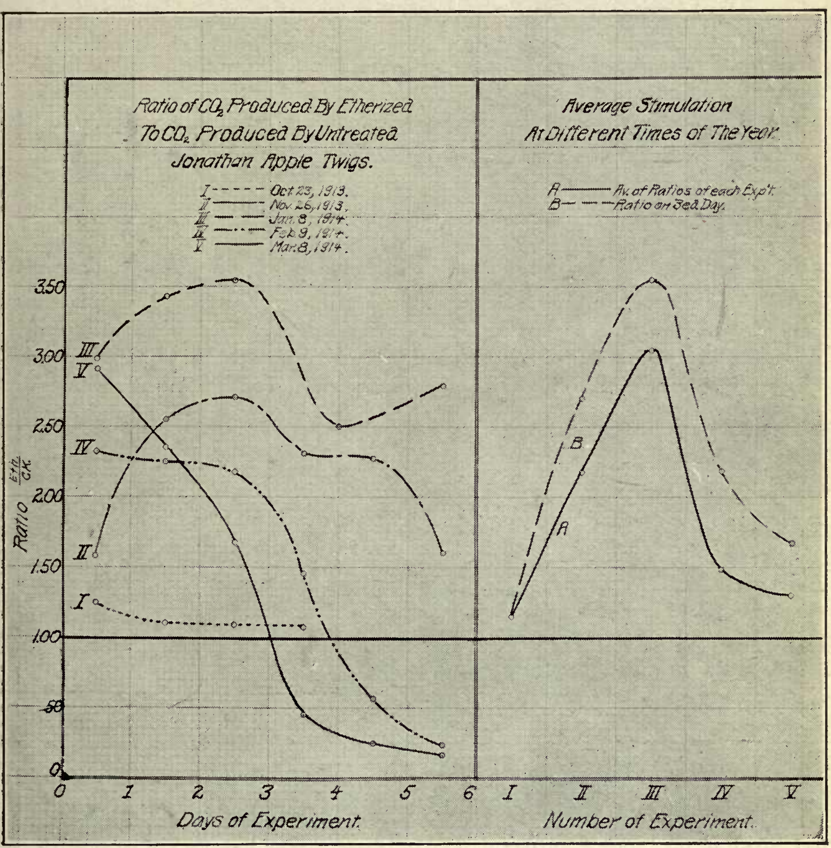

Fig. 6. *Graphs showing the ratio of CO_2 production between etherized and untreated Jonathan apple twigs, together with average stimulation, at different times of the year.*

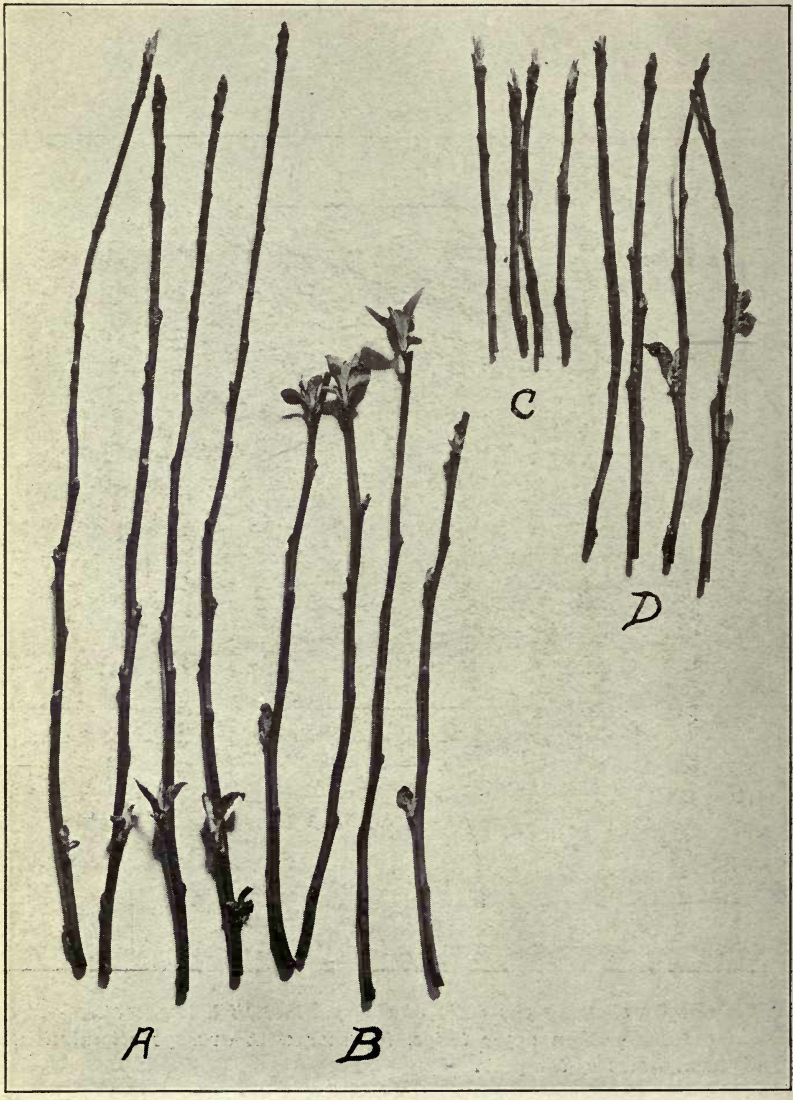

Fig. 8. *Growth of different sections or zones of similar twigs. This illustrates peculiarities of growth following treatments to break the rest period. In some cases terminal buds grew best, while in others the lateral buds are more liable to grow.*

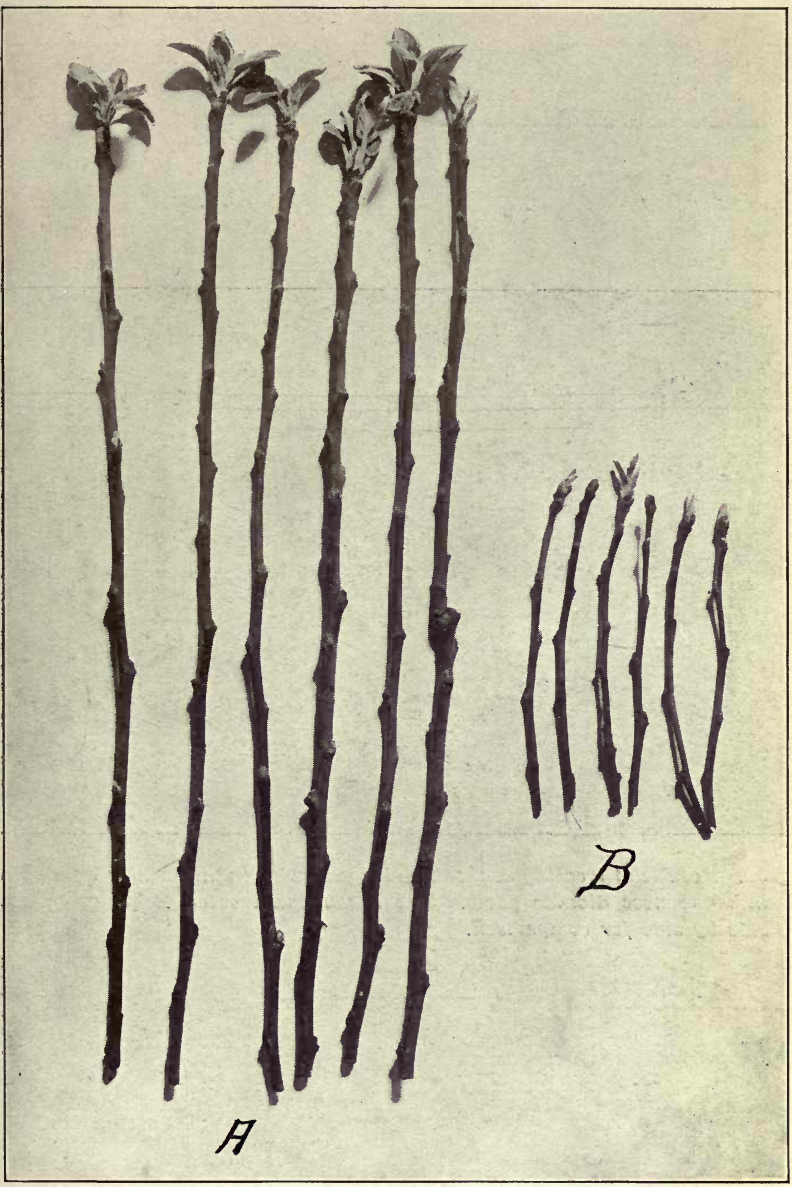

Fig. 9. *Comparative growth of strong and weak apple twigs. Both were placed in the greenhouse without treatment, in late winter. "A" and "B" show the growth that had taken place in the strong and weak twigs, respectively, after one month.*

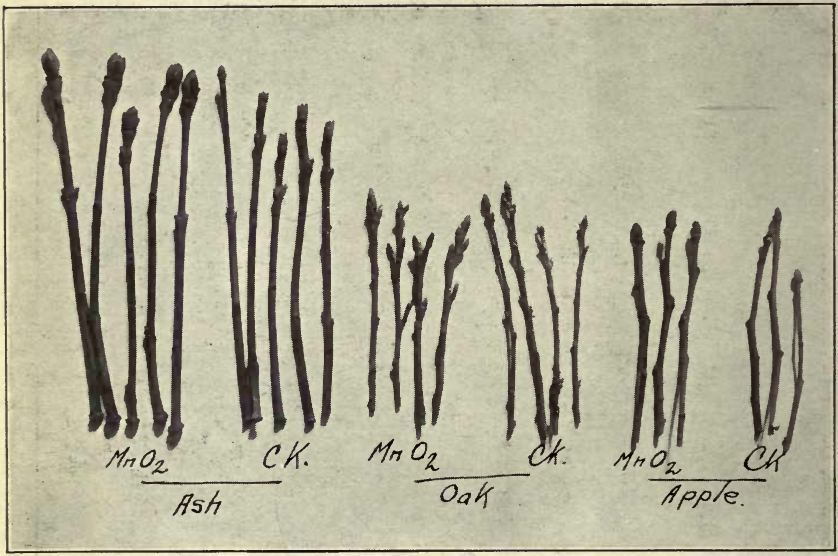

Fig. 10. *Results of treating ash, oak and apple twigs in mid-winter by dipping in manganese dioxide paste. The check and treated twigs are placed side by side for comparison.*

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University of Vermont and State Agricultural College

Vermont Agricultural Experiment Station

BURLINGTON, VERMONT

STUDIES IN TOLERANCE OF NEW ENGLAND FOREST TREES

III. DISCONTINUOUS LIGHT IN FORESTS

by G. P. BURNS

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BULLETIN 193: STUDIES IN TOLERANCE OF NEW ENGLAND FOREST TREES

III. DISCONTINUOUS LIGHT IN FORESTS

By George P. Burns

Introduction

At present the only measure of the so-called "tolerance of forest trees" is the appearance of trees as they grow under the influence of the physical and biotic factors of a given habitat. If the trees are developing slowly, they are "intolerant"; if they are developing rapidly, they are "tolerant."

The factors then that determine "tolerance" are the factors of the habitat; and any study of forest succession, whether natural or artificial, requires an analysis of all those factors, of which light is only one. Upon entering the forest, the lowered intensity of the light is strikingly manifest. No other physical factor is so markedly altered. Hence one naturally associates the variation in the forest vegetation with the light conditions. A poorly developed lot of seedlings is supposed to result from the weakened or filtered light under the dominant trees; and the suppressed trees are supposed to be suppressed because of the changed light conditions.

Zon and Graves (16) in a discussion of the relation of light to tree growth have stated admirably the problems of tolerance. They cite literature indicating that many factors other than light influence tolerance. These authors conclude that we are "far from a thorough understanding of the effect of light upon the individual tree and especially on the trees in the forest." Almost every page suggests problems in plant physiology which must be solved and their work is well adapted to "stimulate an interest in further research in determining more accurately the light requirements of our forest trees, especially by measurements of light in the forests."

Fricke (5) dug ditches around certain plots thus relieving the "suppressed" trees growing thereon from the competition which existed between their root-systems and those of the dominant trees. Not only did vigorous young seedling trees grow in these isolated plots, but there also appeared a "luxuriant herbaceous vegetation strikingly different from that in the surrounding forest." The forest cover was not altered and without any change in the light conditions, the suppressed vegetation began a vigorous growth, seeming to indicate that "root competition"was at fault rather than light shortage in cases of suppression. Hartig (8) says that, on a good soil, a given number of leaves will produce more substance than will the same number of leaves on a poor soil. "The growth of a tree may suddenly double or treble without increase in leaf surface or light intensity if the nourishment of the roots is greatly increased." He thus clearly recognizes soil conditions as a limiting factor in the growth of trees.

Tolerance, then, in the strict and proper sense of the term, represents the ability of a tree to thrive under the conditions of soil moisture, light, humidity, etc., found in any given habitat. However, this word is so established in our literature as expressing a light relationship only, that it will be difficult to superimpose the meaning just indicated. A clear understanding of the problem of forest succession and forest reproduction would be more easily attained in all probability if the word were elided from forestry literature.

LIGHT MEASUREMENTS IN FORESTS

The present bulletin attempts to determine the value of "light measurements in the forest" and to determine their significance in a study of the light requirements of our forest trees.

Light reaches the forest floor in four ways, through the tree crowns, between the tree crowns, reflected from leaves and twigs, and through the leaves themselves. The light which passes through the leaves is altered in composition; the rest is white light. Obviously, then, the kind and intensity of light vary greatly in forests of different species of trees.

The study of light intensities in the forests has been made along two distinct lines, according as the workers have emphasized the importance either of weakened white light or of filtered light in forest growth and reproduction and in the development of the vegetation of the forest floor.

FILTERED LIGHT IN FORESTS

Zederbauer (15) made a study of the light which passed through the leaves of several different species of plants and found that there was some variation in the rays absorbed. He argued therefore that the light in the forest must be altered in composition as it passes through the crowns. Accordingly he undertook to study the light in forests with a spectroscope. The stations selected were located in pure stands with the first branches ten meters from the ground and were situated

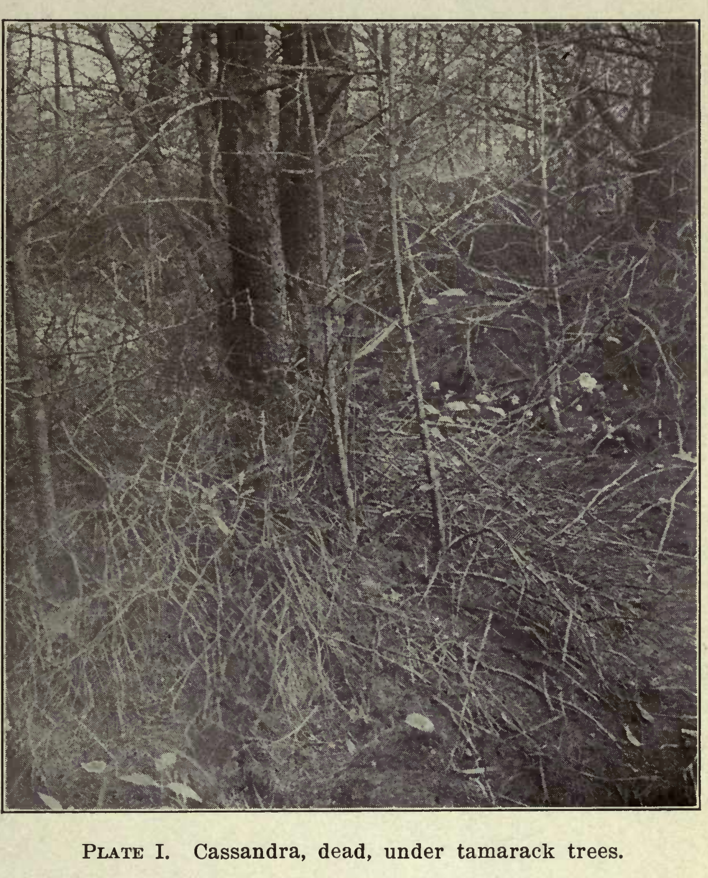

Plate I. Cassandra, dead, under tamarack trees.

Plate II. Taxus canadensis. At times a few rays of sunshine reach into the deepest recesses.

Plate III. Reproduction of maple along the roadway running north and south. The seedlings receive full light during part of the day and are relieved also from competition with the roots of the adjacent forest trees.

far enough from the forest margin to be beyond the influence of side light. He found that all trees absorb between Frauenhofer lines B and C in the red end of the spectrum, then in the region about F in the blue, and beyond H in the violet. Some tree species absorb practically all rays from F to H, while others allow many rays in the indigo region to pass through unabsorbed. Intolerant pine and larch absorb about the same in the red, blue, and violet sections, using practically all the red, but only small amounts of blue and violet. On the other hand the tolerant spruce and beech, besides red, absorb some orange and a large amount of blue, indigo, and violet rays. Ash and oak fall between these two extremes and allow many indigo rays to pass through unabsorbed.

Zederbauer's results, in part at least, are admitted to be inaccurate, because of defects in the apparatus. It will appear later that many other errors must be eliminated before reliable results can be obtained. The fact that leaves of various species of trees absorb different rays of light is interesting, but of itself proves nothing.

Knuchel (10) undertook an exhaustive study of this subject and published a great mass of data which was reviewed by Sponsler (13). His methods were much more refined than those of Zederbauer, and his results are accordingly more trustworthy. His study was devoted especially to the variations in the composition of light which had passed through leaves, through forest crowns and through individual crowns. In the first case he used both sun and shade leaves of basswood, beech, ash, maple, etc. On account of their size no attempt was made to use softwood leaves. Only one illustration of his work with leaves need be given. On July 8, 1911, he took measurements of the composition of diffuse light after it had passed through leaves of the beech and obtained the following results:

TABLE I—COMPOSITION OF LIGHT AFTER PASSING THROUGH BEECH LEAVES (KNUCHEL)

Rays passing	Sun leaves		Shade leaves	
	One leaf percent average	Two leaves percent	One leaf percent average	Two leaves percent
Red	2.5	0	11	2
Yellow	13	0	18.5	3
Green	6	0	16.5	1
Light blue	2	0	5	0
Dark blue	0	0	1	0

Since the sun leaves receive the light first and use the greater part of it, it would seem reasonable to assume that the filtered light is not of much use to the leaves within the crown.

Both hardwoods and softwoods were employed in Knuchel's study of the composition of light in the forests and under single trees. Some of the former consisted of beech, ash, birch and basswood, the latter of spruce, Scotch pine and silver-fir. He set up his spectroscope and made readings in the open. He then moved it into the forest to a previously selected typical or average station and made readings for that forest. Comparisons should enable one to determine the proportion of the total rays absorbed by the crowns. The subjoined table is typical, both for forest and single trees.

TABLE II—COMPOSITION OF LIGHT UNDER CROWNS OF BEECH AND SPRUCE (KNUCHEL)

Beech	Single tree (heavy crown) Single reading percent	Forest Young stand Average reading percent	Old stand Average reading percent
Red	1	3.5	4.5
Yellow	4	6.6	6.4
Green	3	5.4	4.9
Light blue	1	2.6	3.6
Dark blue	1	2.4	3.1

Spruce	Grade A Average reading	Grade B-C Light clearing Average reading	Heavy clearing Average reading
Red	4.2	13.8	33.2
Yellow	5.2	14	33.7
Green	5.5	13.2	34.8
Light blue	4.1	12.5	32.8
Dark blue	4	12.4	32

Knuchel finds that the light under the crowns in hardwood forests has a similar composition to that passing through the leaves of the species composing the forest. The exception found was in the presence of blues in the former case. These blues, he says, come through the openings within the crowns. Under softwoods he found no color especially prominent, the light possessing the same composition as the light in the open; that is to say, no selective absorption was observed.

The present writer doubts whether valuable data can be obtained by the use of the spectroscope in the forest. It seems to him quite clear that the selection of a forest station for spectroscopic work which will represent the average of the forest cover and at the same time be as small as the opening which admits light to the spectroscope, is a difficult if not an impossible task. Furthermore the trustworthiness of the comparisons of these light values with the observations made in the open is questionable, since many changes both qualitative and quantitative in character may occur in light values while the instrument is being moved to a new location and adjusted. Knuchel points out somewhat in detail this possibility of error.

In the solution of the problem of forest succession, little is gained by showing that the weakened light which passes through the sun leaf is comparatively rich in yellow and green rays, unless it is shown experimentally that this light is able to decompose carbon dioxid and otherwise influence the development of the seedlings of the future forest. Our knowledge of the value of the different rays of light in the development of plants is so rudimentary that great care should be used in drawing general conclusions in view of the lack of experimental data.

Further and valuable observations have been made by other workers in this field who have attempted to discover the amount of light actually passing through the leaves unabsorbed, and, finally, to determine the ability of such light to decompose carbon dioxid. For example Linsbauer (11) has determined the amounts of light which pass through sun and shade leaves of the same species and through sun leaves of different species. His results indicate that more light passes through the shade leaves than the sun leaves of the same species, but that the intensities are greatly reduced as shown by the following table, which represents only a small part of his data.

TABLE III—AMOUNT OF LIGHT PASSING UNABSORBED THROUGH LEAVES (LINSBAUER)

	Sun leaf	Shade leaf
Acer platanoides	.0008	.005
Carpinus Betulus	.003	.008 average
Cornus sanguinea	.0004 average	.003
Fagus silvatica	.0046 average	.02
Fraxinus excelsior	.001	.005
Quercus Robur	.006	.003
Rhamnus cathartica	.003	.008
Ulmus montana	.003	.0075 average

He found that the amount of light passing unabsorbed through sun leaves varies with different species from .006 to .0003, totality equalling 1, and that in the case of shade leaves the figures varied from .003 to .02. For a given tree with both sun and shade leaves, the amount of light passing through the leaf unabsorbed decreased from the center of the crown toward the periphery. If the leaves of the tree were formed to use the greatest possible amount of total light available, exactly the opposite result would be expected. Only in the case of Quercus Robur did the sun leaves allow more light to pass through unabsorbed than did the shade leaves.

Griffon (7) studied the action of the light which had passed through leaves. He placed a privet leaf in a chamber with a known percent of carbon dioxid, usually about 9 percent, and placed over the top one or more leaves of the plants undergoing observation. In this way all the light reaching the privet leaf was forced to pass through the experimental leaf. A gas analysis made at the close of the trial enabled him to determine the amount of carbon dioxid which the privet leaf had used. He thus determined the fact that light which passed through one leaf of many species was still strong enough to decompose carbon dioxid, when present in amounts of 5 to 10 percent, but that the rapidity of the process was greatly reduced by this preliminary filtration. In the sycamore maple this was reduced 48 times, but in the beech only seven times. When two leaves were interposed, no decomposition of carbon dioxid whatsoever took place, save that a very feeble action was observed under the two beech leaves. Such data show that although some light passes unabsorbed through both sun and shade leaves and that in some cases it is able to decompose carbon dioxid, yet the amount which passes is so small that it cannot play an important part in the nutrition of the trees or in forest succession. It would seem probable then that a weakened white light rather than a filtered light is the controlling factor in the development of all trees (14).

WEAKENED WHITE LIGHT IN FORESTS

The intensity of the light falling on the forest floor as compared with the total light in the open has been studied by a number of workers. It is sufficient for present purposes to cite only a few of the results thus far obtained.

First among the students of the matter is Wiesner (14) who adapted the work of Bunsen and Roscoe to botanical research. Using photographic paper[1] he attempted to determine the light values in forests in many parts of the world and also the minimum light requirements for many plants. The following table has been compiled by Zon and Graves (16) from the works of Wiesner "for some of our native trees and shrubs and European species commonly grown here."

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[1] Critics of this method often fail to appreciate the fact that photosynthesis is not the only function of the plant affected by light.

TABLE IV—MINIMUM LIGHT REQUIREMENTS FOR SOME NATIVE TREES AND SHRUBS (WIESNER)

Species	Region	Approximate elevation feet	Minimum light intensity
Pinus contorta	Yellowstone Park, Wyo.	6,400	.1666
P. contorta	Yellowstone Park, Wyo.	8,500	.1562-.1449
P. flexilis	Yellowstone Park, Wyo.	6,000	.1250-.1111
Picea parryana	Yellowstone Park, Wyo.	8,000	.0166-.0161
P. parryana	Salt Lake City, Utah	4,000	.0156-.0143
Pseudotsuga taxifolia	Yellowstone Park, Wyo.	5,500-6,000	.0500
Juniperus virginiana	Yellowstone Park, Wyo.	6,000	.2000-.1428
J. communis nana	Yellowstone Park, Wyo.	6,000-8,000	.1111-.1041
Acer glabrum	Yellowstone Park, Wyo.	6,000	.0333
A. saccharium L.	Niagara Falls, N. Y. (600 ft.) and Pocatello Idaho	4,000	.0400-.0250
Populus alba	Utah and Idaho	3,000-4,000	.1250-.1000
P. tremuloides	Yellowstone Park, Wyo.	6,000	.2381-.1666
P. acuminata	Livingston, Mont.	4,500	.1250-.1098
P. deltoides	Colorado Springs, Colo.	6,000	.2500
P. deltoides	Billings, Mont.	3,100	.1111
P. nigra italica	Salt Lake City, Utah	4,250	.0476
P. balsamifera	Colorado Springs, Colo.	6,000	.0625
Betula fontinalis	Mam. Hot Springs, Wyo.	6,000	.0714
Sheperdia argentea	Yellowstone region near Livingston, Mont.	4,500	.0714
Vaccinium myrtillus	Yellowstone region		.0602

Additional data taken from Wiesner's work appears below.

TABLE V—AVERAGE MINIMUM LIGHT INTENSITY REQUIRED (WIESNER)

Species			Light intensity Average		
Fagus silvatica			0.016		
Acer platanoides			0.018		
A. campestre			0.023		
A. negundo			0.034		
Thuja occidentalis			0.050		
Pinus Laricio			0.099		
Betula verrucosa			0.111		
Populus monilifera			0.166		
Fraxinus excelsior			0.171		
Larix decidua			0.200	0.166	0.250
Picea excelsa	0.050	0.125	0.025	0.016	0.011

These figures represent the averages of many readings. In several cases such large variations in light intensities were found that more than one so-called minimum is given; for example, Acer saccharinum, not given in the table, has values of 0.200 and 0.143. Similar variations are given for Larix decidua. This tree has a so-called minimum of 0.166, 0.250 and 0.200. For Picea excelsa the following values are given: 0.011, 0.016, 0.025, 0.05, and 0.125. In the last case cited the great range in light required from 0.011 to 0.125 would seem to indicate that possibly the method used was not entirely trustworthy.

Clements (3), studying the conditions in mature forests of lodgepole pine, found that the intensity of light in these forests varied from 0.12 to 0.05. He says "the values most frequently found were 0.08 and 0.07 which may well be taken as the normal." His lowest value was 0.016. Germination and growth were fairly good from 0.2 to 0.14, decreasing rapidly below the last named figures. When the light intensities were .08 to .05 there were no vigorous seedlings.

Pearson (12) found western yellow pine seedlings growing in habitats with average light intensities of 0.630 to 0.309. Only in intensities of 0.414 or better were the seedlings marked "good." Especially interesting in the data given for Abies concolor, where there seems to be little connection between the values given and the condition of the growing trees. In an intensity of 0.02 the trees were suppressed, while in light only a little stronger, 0.027 and 0.028, they were marked "good." The trees were doing well in light intensities of 0.048 and 0.068. This lack of uniformity in light requirement for the seedlings in each of these species must be due to some factor other than light, or else the method used is not trustworthy.

The following light values were taken from Pearson's readings, as given by Zon and Graves (16).

TABLE VI—LIGHT VALUES FOR WESTERN TREES (PEARSON)

Condition of seedlings	Pinus ponderosa Average light intensity	Abies concolor Average light intensity	Pseudo tsuga taxifolia Average light intensity
Good	.630	.068	.192
Good	.570	.048	.133
Good	.414	.028	...
Good	...	.027	...
Fair	.385	...	.097
Fair	.309	...	...
Poor	...	...	.049
Poor	...	...	.016
Suppressed	...	.020	...

Hesselman (9) noted great variations in light intensity under the shade of the plant groups which he studied. In some cases these variations amounted to as much as 300 percent. In groups of old spruces the light intensity was reduced to 0.044 and 0.037; in young spruce these values were 0.020 and 0.016.

Ciesler (2) measured light intensities in several types of forests, in each of which he took measurements after three grades of thinning. He found that forests which had been only lightly thinned held back a surprisingly large proportion of the light. The crowns of a severely thinned stand of fir absorbed about 80 percent, a beech stand 80 to 90 percent, and Austrian pine about 60 percent of the total light. In a beech stand which had been lightly thinned the crown absorbed 93 percent and a stand of Austrian pine similarly treated absorbed 80 percent.

The measurements here recorded vary so widely in respect to the so-called minimum that it would seem as if the accuracy of the method must be open to question.

LIGHT READINGS

The light values given in this section of the bulletin were made by the writer or his pupils, with the Clements type of photometer. This is a modification of the Bunsen-Roscoe-Wiesner instruments with which it is possible to make 25 separate readings in the field for each instrument. On account of its size and ease of operation it is adapted admirably to studies in the field. The usual method of operation is described by Clements (4) and need not be repeated here. In our work three persons were used in making the standard, one with a stopwatch, the other two with photometers. Exposures of from one to 25 seconds were made. Whenever possible this standard was made at actual noon on June 21; if clouds intervened at midday, on the first succeeding clear day. In the work done at Camp Bogardus, Douglas Lake, Mich., the standard was made the first clear day after work began. One of the strips of solio paper thus exposed was taken as the standard, glued to cardboard on which was indicated the length of exposure for each of the 25 tints thus obtained, wrapped in black paper and stored in a pasteboard box in the dark room where it was well protected from light and heat and showed little or no change during the season.

In actual work the readings taken in the field are compared with the standard in order to determine the light intensities. The matching of colors was done usually by one and the same person in order as much as possible to eliminate its personal equation. However, repeated tests made with several individuals have shown that appreciable difference in the light intensities as thus determined are uncommon. Hence it is safe to assume the essential accuracy of the observation. The light values determined when the standard was made were given the value "1," and all data were figured to this basis.

It is extremely difficult to get reliable data on the light intensity in the forest because the forest cover is not uniform, the light varies greatly within short periods of time, more particularly because of passing clouds, and there is no satisfactory instrument which will record accurately the light values during an entire day. As has been pointed out, there are many openings in the crowns of the individual trees and between the crowns of the adjacent trees, which cause an uneven shade on the ground. Indeed marked variations occur within a few feet. On this account great care must be taken in making exposures. In the studies now under review while making exposures in woods which were free from shrubs, the operator walked back and forth over a distance of 50 feet. The photometer was so held that the shadow of the body did not fall on the instrument at any time. In other habitats it was impossible to move the photometer through so great a distance, but in no case was it held stationary while an exposure was being made. Nevertheless despite precaution it is impossible to select an average station, for the personal equation is bound to be an all-important factor in its choice.

Absolutely cloudless days are few and far between in Michigan and Vermont. To be convinced of this fact one has only to attempt to make a study of light intensities. He will be struck with the fact that slight clouds pass almost continuously. Light variations which one would not notice ordinarily nevertheless are quite marked, even within the space of a few minutes. On this account, especially in the work of the past three years, simultaneous readings have been made. One person was left in the open control station while others went to the forest stations. If watches are compared and definite times for exposures are agreed upon, simultaneous readings can be made, even at stations which are widely separated. The lack of simultaneous readings is a serious source of error occurring in and vitiating much of the published data on light studies which are now extant. Knuchel (10) recognized this limitation of accuracy in his own work but was unable to rectify it because he did not have access to a sufficient number of instruments to enable him to make simultaneous readings. In the earlier work, before the need of simultaneous readings was felt so keenly, the author made observations at close intervals, usually five minutes apart, in order to avoid as much as possible the error due to changing light intensities in the open.

Even the velocity of the wind has been found to introduce errors in the readings taken in the forest, especially in hardwood forests. The movement of the leaves is an important factor in determining the amount of light passing to the interior of the crown or to the ground cover.

Undoubtedly one of the most serious errors in much of the published data on light intensities is due to the fact that many workers have taken their readings in the middle of the day and on bright clear days. Such readings, of course, are of little value in determining the amount of light available in a given habitat. However, intensities, measured at that time of day may be lower than those to be found in the same habitat earlier or later in the day. Some observations have shown that the maximum may be found before 9 A. M. or after 3 P. M. This is due to the fact that the sun, at different angles, throws varying amounts of light on a given habitat in the forest.

The data reported in this bulletin were gathered:

(1) At First Sister Lake, a small post-glacial pond near Ann Arbor in Washtenaw County, Michigan, latitude about 42° 20′.

(2) In the forests surrounding Douglas Lake, Cheboygan County, Michigan, latitude about 45° 30′.

(3) Near Burlington, Vermont, latitude about 44° 30′.

1. FIRST SISTER LAKE

The vegetation of the bogs of the post-glacial lakes of southern Michigan has been described by several writers. A description of the conditions at this lake has been published somewhat in detail by the writer (1), who pointed out that the vegetation was arranged in zones, three of which were characterized by the dominance of certain trees, namely the Larix, Populus-Acer, and Salix. In some of these zones were found areas in which trees of other zones are prominent, for example Larix-Populus areas; in other places a pure stand of Populus was found which occupied a small area. Except in some parts of the Larix zone, more especially on the side toward the lake, the vegetation is not very dense. Most of the trees are small and the vegetation under them is quite abundant.

For a study of the light conditions in the tree zones, under the shade of the trees, the following stations were established; Control, Larix, Larix-Populus, Populus, Populus-Acer, and Salix. Readings were taken five minutes apart in most instances, beginning each day with the control station which was located near the water's edge. On some days and at some stations, five minutes or less was sufficient in which to make a reading, but in other cases 10 minutes or even more were necessary. Since there are six stations, it required a minimum of somewhat less than 30 minutes in which to take the readings and in many cases more than 60 minutes passed between the reading in the control and that of the Salix station.

The readings were taken at about the same time of day and the areas through which the photometer was moved were as nearly the same each time as could be estimated.

The result of this work is displayed in table VII. The values there given are directly comparable, as they all refer to the common standard, 1. In this instance the standard was made on April 27, a rather early date; but it seemed at that time desirable to make comparisons while the solio-paper used in making the readings was still fresh.

TABLE VII—LIGHT INTENSITIES AT CERTAIN STATIONS IN A PEAT BOG, COMPARED TO A COMMON STANDARD. MOST OF THE TREES WERE SMALL, AVERAGING ABOUT 30 FEET. FIRST SISTER LAKE, ANN ARBOR, MICH.

	April				May				
	5	11	19	27	3	10	17	24	31
Open	.0666	.2000	.6666	.8000	.5333	.5666	.1700	.2166	.5000
Larix	.0250	.0466	.0400	.2500	.1166	.1333	.0440	.0255	.0917
Larix-Populus ..	.0555	.1250	.7500	.6500	.4666	.4666	.2170	.1700	.3660
Populus	.0555	.1250	.4666	.3000	.2666	.3666	.1361	.1060	.1000
Populus-Acer ...	.0666	.1580	.6433	.6666	.3666	.5166	.1700	.2111	.2000
Salix	.0611	.1333	.3333	.6000	.3333	.4000	.2110	.1700	.2000

A careful consideration of these figures shows a wide divergence in the light intensities existing in the different zones when these are compared with one another. The only zone with consistently low intensities was the Larix, in which case variations ranged from .125 to .1333. In an adjacent Larix station, in which the cover vegetation was Cassandra in a dying condition, a series of readings gave a maximum light intensity of only .0333. (Plate 1). April 5 was a cloudy day with a light intensity of .0666 at the control station. A comparison of the values at other stations shows that with the exception of the Larix station there was very little variation. The same fact is apparent, but not so striking, in the data secured on May 17. On brighter days greater variations occurred, as may be seen by examining the data for April 27 and May 31. Possibly these wide variations are due to the fact that it is impossible to expose the photometer in exactly the same place when it is moved under the tree crowns. All possible care was taken to avoid error of this kind, but, as has been pointed out already, exactness in this respect cannot be obtained.

In some instances the light intensity "in the shade" was higher than in the open. (April 19, Larix-Populus station; May 17, same station and Salix station). Such occurrences tend to raise a doubt as to the actual value, indeed of the accuracy, of other readings. They are due, of course, to variations in the density of the clouds at the times when different readings were made. These data emphasize the importance of simultaneous readings in any region where clouds occur.

It seemed desirable to determine the percent of light which was cut off by the various trees. The light value in the open each day being regarded as 1 and the readings taken at other stations figured to this basis, the data are presented in table VIII. The effect of the cover here is seen easily. If it is assumed, as is done usually, though without warrant, that the light intensity in the open did not vary while the six readings were being taken, the figures represent the amount of light that was held back by the trees.

For example, if on April 27 the light in the open is 1, then the crowns of Larix cut off 69 percent of the light, Larix-Populus 19 percent, Populus 63 percent, Populus-Acer 17 percent, and Salix 25 percent. A month later, however, on May 31, 82 percent, 27 percent, 82 percent, 60 percent and 60 percent were thus shut out. These consistent increments in shade may be due in part to the fact that the trees were more fully in leaf at the end of May than they were in late April. However, this fact cannot account for the variations found in comparing values obtained May 24 with those of May 31.

TABLE VIII—SHOWING THE AMOUNTS OF LIGHT HELD BACK BY THE TREES

	April				May				
	5	11	19	27	3	10	17	24	31
	%	%	%	%	%	%	%	%	%
Open	0	0	0	0	0	0	0	0	0
Larix	63	77	40	69	79	77	75	89	82
Larix-Populus ..	16	38	*	19	13	17	*	25	27
Populus	16	38	31	63	50	36	20	52	82
Populus-Acer ..	0	21	4	17	32	9	0	3	60
Salix	9	34	50	25	38	30	*	25	60

*Light stronger than it was in the open.

2. DOUGLAS LAKE

During the summer of 1909 the writer spent some time with advanced students studying the forest conditions in the neighborhood of Douglas Lake, Cheboygan County, Michigan, with a laboratory at Camp Bogardus. The camp was located at the edge of the lake and was in easy reach of several types of forests.

A general survey of the region indicated the existence in a general way of four types; Acer-Fagus-Tsuga, Thuya-Fraxinus-Ulmus, Larix, Populus—Betula papyrifera. Near the camp was a very deep ravine which widened rapidly toward the east. A series of springs yielding a daily flow estimated at 3,000,000 gallons, empties at the head of the ravine. This water flows in a more or less well defined channel into Burt lake. Seven stations in close proximity were located near the head of this ravine. These were designated as Acer, Fagus, Tsuga, Taxus, Mnium, Pinus strobus, and Acer rubrum. As one leaves the hot sandy plain above and descends the steep winding path to the shady ravine, a drop of about 68 feet, physical conditions change rapidly. The relative humidity as determined by an average of eight readings, increase from 53 percent in the control in the sand plain to 83 percent in the ravine bottom; the air temperature at the surface of the soil decreases from 35° C. to 18° C., while on hot days the difference amounts to as much as 30.5° C.; soil temperatures decrease, and light intensities are enormously reduced. The change in midsummer is most delightful.

Of the considerable amount of data recorded, only those dealing with the light intensities will be considered here. The prevailing trees at the first five stations are Acer, Fagus, and Tsuga. At the Mnium and Taxus stations Acer spicatum and Acer pennsylvanicum also occur. Under these, light intensities were extremely low; nevertheless at times the sun was able to send a few beams of direct sunlight into the deepest recesses. (Plate 2).

The reading in the Pinus strobus area showed a much greater light intensity and also much wider variations than at the other stations. The lowest reading taken on a bright day with light intensity in the open at 1 was .0625; on two other days it was .75. The table shows that similar variations in light intensities were found at all stations when the light in the open was 1. At the Mnium station under cover of trees and shrubs, the light was almost four times as strong on July 19 as it was on August 12.

Table IX shows very clearly that marked variations may occur in light intensities at the same station. This is due chiefly to a very discontinuous forest cover.

TABLE IX—LIGHT INTENSITIES NEAR BIG SPRINGS, DOUGLAS LAKE, MICHIGAN

		July			August		
		19	22	29	5	9	12
I	Open............	1.0000	.2500	1.0000	.6666	.5000	1.0000
II	Acer-Fagus-Tsuga	.0083	.0133	.0083	.0083	.0033	.0022
III	Acer-Fagus-Tsuga*	.3333	.0625	.3750	.1250	.1666	.1666
IV	Acer-Fagus-Tsuga		.0166	.0333	.0277	.0222	.0277
V	Taxus canadensis	.0083	.0277	.0416	.0277	.0416	.0555
VI	Mnium sp.	.0083	.0055	.0083	.0083	.0083	.0022
VII	Pinus strobus ..	.0625	.1666	.7500	.1666	.1500	.7500
VIII	Acer rubrum ...	.0125	.0277	.0833	.0416	.0416	.0416

*The high light intensities at station III, located at the bottom of the park leading to the springs, as compared with stations II and IV, are due to a clearing.

In table X an attempt is made to show the effect of the forest cover on bright days as compared with cloudy days. Light in the open varied from .25 to 1. The light values in the open were figured as 1 in every case and the percentage of light at each station computed. These data sometimes are confusing rather than helpful. They conceal important differences in intensity. For example at the Taxus station the forest cover reduces the light intensity on July 22 to .0277, (Table IX), or it holds back 89 percent of the total daylight at that time. On August 12 the light intensity is .0555, and 94.5 percent of the total daylight has been held by the cover. Nevertheless the plants on August 12 have twice as much light for their development as they had on July 22.

TABLE X—REDUCTION IN LIGHT DUE TO VEGETATION EXPRESSED IN PERCENTAGE OF LIGHT IN THE OPEN. DATA GATHERED NEAR BIG SPRINGS, DOUGLAS LAKE, MICHIGAN

		July			August		
Date		19	22	29	5	9	12
Actual reading in open ..		1.	.25	1.	.6666	.5	1.
Reduction in percentage by shading		Percent	Percent	Percent	Percent	Percent	Percent
I	Open	0	0	0	0	0	0
II	Acer-Fagus-Tsuga ..	99.2	96	99.2	99.8	99.4	99.8
III	Acer-Fagus-Tsuga	66	75	62.5	82.3	66.4	83.4
IV	Acer-Fagus-Tsuga ..		93.4	96.7	95.9	95.6	97.3
V	Taxus canadensis .	99.2	89	95.9	95.9	91.7	94.5
VI	Mnium sp.	99.2	97.8	99.2	99.8	99.6	99.2
VIII	Pinus strobus	93.7	33.3	25	75.1	97	75
IX	Acer rubrum	96.2	89	92.7	93.8	91.7	95.9

Only a few data are available for studying the effect of forest on light intensities as they vary from hour to hour with the changing of the sun. Two cases are cited by way of example, but since in these trials it was not possible to take simultaneous readings, an unavoidable source of error was introduced. Four readings taken an hour apart under an Acer-Fagus-Tsuga cover show that the crowns cut off 60, 93, and 81 percents of light respectively. These figures represent a variation in light intensities of from .0166 to .3000. At the time of the latter intensities, the numerous seedlings of Acer and Tsuga had a sufficient light for all purposes. In an adjacent stand of Tsuga, the morning readings were 94 and 95 percents, which show a fairly uniform cover for that period. (Plate IV).

Numerous seedlings of Fagus and Acer were found in habitats the light intensities of which were .0250 and even lower. That higher light intensities with proper moisture conditions are favorable for their development, can be seen by a comparison of the reproduction in deserted road-beds with that of adjacent areas. These wood-roads receive the full sunlight for a few hours at least on each bright day. Acer seedlings which cover the roadway are as thick as if grown in a seed-bed, whereas very few are found in the woods three rods away where the light was much weaker and root competition with the old stand of trees was more intense. (Plate III).

The data presented emphasize the fact that in the natural woods variations may occur in the amount of light available for seedlings, that in other words the intensity of the forest shade is an extremely variable factor. (Plate V).

3. BURLINGTON

In order to determine the relation of crown cover to the surface of the forest, a series of studies was started in definite areas. These areas were 100x100 feet and were subdivided into 100 squares, each 10x10 feet, the boundaries being marked with common wrapping cord. Then a map of the area was made, locating the size and kind of each individual tree, after which the crown was projected upon the ground and mapped. In some instances shrubs and herbaceous forms also were shown.

These maps and the data previously given show that there is considerable variation in the amount of light reaching the surface under a forest. The attempt was made now to determine the total light that would fall on a group of seedlings during the day, but in view of the lack of satisfactory self-recording instruments this was found to be a very difficult problem. The most satisfactory way seemed to be to determine as accurately as possible by the use of a camera how much light fell on a given point, a method which has been suggested by Frederick (6), but has not been used to any great extent. With the camera located at one and the same point, eight 5x7 plate exposures were made in the college woods on August 3, 1912, beginning at 2 P. M. The camera was pointed successively due east, southeast, south, southwest, west, upward with an eastern angle, directly upward and, finally, upward with a western angle. The first five exposures were meant in a way to follow the course of the sun across the sky. Velox prints were made and the light patches removed, as nearly as this was possible. In some instances it was necessary to estimate the amount to be cut out because of the fine branches and leaves.

The data are given in table XI.

TABLE XI—LIGHT DATA TAKEN IN THE COLLEGE WOODS BY USE OF CAMERA

	Original weight of paper grams	Final weight of paper grams	Shade percentage	Light percentage
East	2.970	2.690	90	10
Southeast	3.046	2.400	78	22
South	3.021	2.221	73	27
Southwest	3.062	2.370	77	23
West	3.038	2.801	92	8
Upwards eastern angle	2.885	2.395	83	17
Upwards	3.136	2.160	68	32
Upwards western angle	3.067	2.580	84	16

These figures show that during the day a considerable amount of light penetrates to the ground cover, despite the fact that the forest cover eliminates a large percentage. They also show how useless it is to attempt in such a place as a forest to determine available light for seedlings by means of isolated readings.

The photometer readings for the station near this location for the summer gave an average light value of only .0554 above some small white pines and .0374 below these pines. Table XII displays the average of a large number of readings taken in the natural forests of Pinus strobus or Tsuga near Burlington, together with reproduction statements.

TABLE XII—AVERAGE OF READINGS NEAR BURLINGTON

Location	Light intensity	Seedlings
Williston		
Pasture	.6766	none
Forest	.0266	none
Burlington, forest chiefly Pinus strobus		
Level ground	.0154	many
Level ground, above 3-foot seedlings	.0554	
Level ground, under 3-foot seedlings	.0374	some
South slope	.0278	none
North slope, above herbaceous plants	.0364	
North slope, under herbaceous plants	.0069	many
West slope	.0246	none
East slope	.0088	none

The data in table XII show no marked relationship between light intensities and the presence of seedlings. At one station the average reading was only .0069, yet the ground was well covered with seedlings whereas none grew at a nearby station where the light intensity was .0088 or a quarter greater. Seedlings were growing in this woods at stations where light intensities were .0374, .0069 and .0154; but none grew at adjacent points where light intensities were .0278, .0246 and .0088.

A study of the foregoing tables soon convinces one that the present methods of determining light values in the forest are unsatisfactory. Too little attention has been paid to the fact that the so-called shade is a discontinuous shade and a constantly changing factor. The variations in light intensity due to clouds, the impossibility of making equal exposures in repeated readings, the variability of the forest cover thus requiring the operator to choose a "typical station for the forest under consideration," and the habit of reading only on bright days about noon; all these make for inaccuracy and emphasize the difficulty, if not impossibility, of determining the relation of forest trees to light by a "study in the forests."

The results of the work in the forests showed the necessity of devising a habitat wherein continuous shade may occur. Accordingly a series of frames was made of 1x1 inch lumber, each frame being two inches larger than the one preceding it in the stack. The smallest frame was 18 inches square. The larger frames were somewhat bulky, but by using iron braces at the angles a sufficient rigidity was preserved. Seven of these frames were covered with white cheesecloth, 36 threads to the inch, and several with similar cloth which had been dyed black.

A ditch large enough to admit the arm of the operator was dug under the north side of the frame or frames. When his arm was in place with the photometer under the covers, a black cloth was packed around it completely filling the space between the arm and the ditch to keep out all light from entering around the arm. While a reading was being made under the shades, a second operator made a simultaneous reading in the open. When several covers were used a long time exposure was found necessary, and two or more readings were made in the open to compare with the reading under the covers, thus taking cognizance of possible changes in total light which might occur during the interior exposure. Readings were taken on both clear and cloudy days. Table XIII may be taken as a sample. It displays a series of readings taken between 12 and 12:35 on August 16, 1912, when the sky was cloudless and the light in the open was 1.

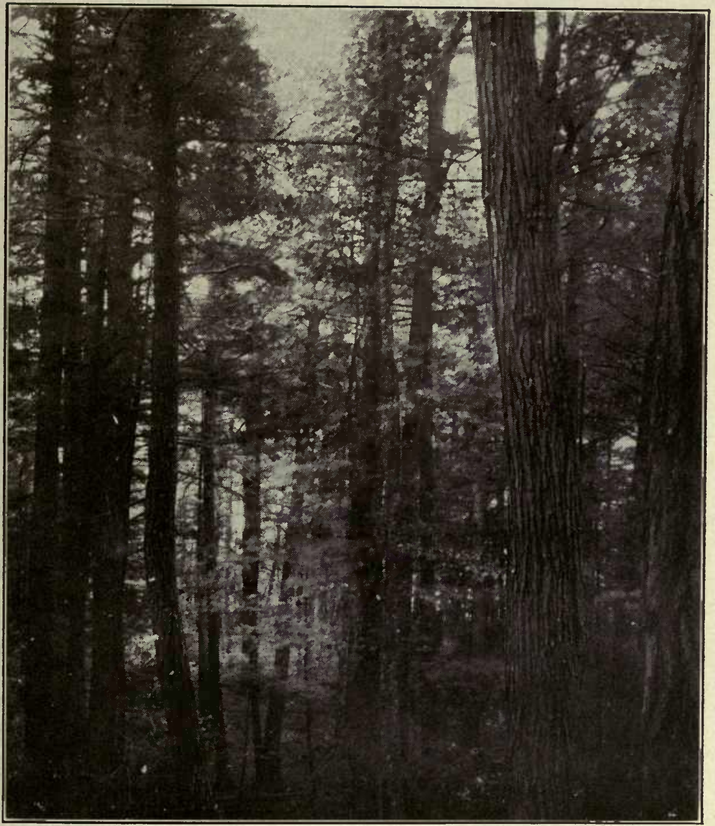

PLATE IV. Discontinuous shade in a dense stand of hemlock near Douglas Lake, Michigan.

Plate V. View in maple, beech, hemlock stand near Douglas Lake, Michigan.

TABLE XIII—LIGHT INTENSITIES IN CONTINUOUS SHADE PRODUCED BY CHEESECLOTH COVERS ON A CLEAR DAY

Light Intensities		
In the open	Number of white covers	In the shade
1	1	.4000
1	2	.2220
1	3	.1666
1	4	.1250
1	5	.0833
1	6	.0625
1	7	.0500

Similar data to that in the last table are displayed in table XIV, except that the readings were taken on a cloudy day between 12:04 and 12:26 M. August 14, 1912.

TABLE XIV—LIGHT INTENSITIES IN CONTINUOUS SHADE PRODUCED BY CHEESECLOTH COVERS ON A CLOUDY DAY

Light Intensities		
In the open	Number of white covers	In the shade
.4999	1	.2222
.4333	2	.1333
.5666	3	.0833
.5666	4	.0555
.4333	5	.0417
.4999	6	.0333

A continuous shade of any desired percent of total light, within certain limits, can be maintained during the entire experimental period. In this shade a series of trials was conducted to determine the minimum light intensity at which white pine, balsam fir, and hemlock seedlings could produce starch, the plants being grown under the screens. It was found that when the light intensity was so far reduced as to register .0266, no starch whatever could be detected in the leaves in the white pine. The hemlock seemed to reach its minimum at about .005. No starch could be found in plants from under two black and four white screens, whereas traces of starch were found in these plants under one black and seven white screens with the same light intensity. These trials are being continued using several more varieties.

It is becoming increasingly evident that the relation of forest tree growth to the light environment can be solved only by carefully planned and executed experiments in the greenhouse and nursery where it is possible, to some extent at least, to control the factors influencing plant growth. We cannot hope that much new information will be obtained concerning this intricate subject by "a study of light in the forest."

The writer has under observation one-year-old seedling trees of white pine which grew in the summers of 1914 and 1915 under large cheesecloth shades which reduces the light approximately to the values shown in tables XIII and XIV. One set was transplanted to give each tree space for the development of its root system; the other set was left as they came up after broadcast sowing.

A comparison of the size, color and general vigor of the two sets seems to indicate beyond a doubt that the chief factor of the slow development of the latter set is not lack of light but some other factor, possibly root competition for water and food in the soil.[1]

CONCLUSIONS

1. The word "tolerance" should be stricken from the vocabulary of forestry students unless to it can be accorded a more comprehensive definition. It is taken generally to express a light relationship, but really it expresses not a light relationship, but the total relationship of a tree to all factors of the habitat.

2. The filtered light in the forest has little value as a means of decomposition of carbon dioxid; the important light in the forest is weakened white light.

3. Light intensity data thus far published in forest light studies as a rule are averages of many readings, usually taken without reference to check readings in the open. They have been taken commonly on clear days about noontime and consequently readings usually are too high. Furthermore, the fact that shade in the forest is discontinuous is additional evidence of the untrustworthiness of much of the published data.

4. The relation of tree growth to light as an influencing factor can be determined only by controlled greenhouses and nursery trials. Light readings in the forest are of little value.

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[1] The writer is well aware of the fact that these cheesecloth shades have a decided influence upon all factors of this artificial habitat. Continuous records of changes in humidity, air and soil temperatures were taken during the season. Rainfall, soil moisture, and evaporation data were also collected. These figures will be published after further experimental data are available.

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NEW HAMPSHIRE COLLEGE
AGRICULTURAL EXPERIMENT STATION

SOME OBSERVATIONS ON THE GROWTH OF APPLE TREES

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SOME OBSERVATIONS ON THE GROWTH OF APPLE TREES.

J. H. Gourley.

The present paper contains some observations on the growth of mature apple trees growing under different systems of culture for a period of nine years. In addition to recording the annual growth we have also made daily growth measurements for three seasons—1913, 1914 and 1916, which are here presented in connection with certain external factors which influence the growth of plants. Soil temperature and moisture, air humidity and temperature, and rainfall have been carefully recorded in this orchard which adds to the interest of the daily growth behavior. Since these data represent 43,000 measurements during three seasons they give us a pretty accurate knowledge of the way these trees behave under field conditions with no attempt made to control the external factors.

SUMMARY.

1. Soil temperature runs lowest under the heaviest vegetation and highest under clean culture during the summer and reverses this order during winter in the orchard under observation.

2. In the ninth year of this experiment the trees under a system of cultivation with cover crops exceeded in annual twig growth the trees in sod by 80 per cent. All the plots receiving a complete fertilizer in addition to cultivation and cover crops showed a marked increase in twig growth after the sixth year of the experiment and in the ninth year these plots averaged 26 per cent greater twig growth than the plot without fertilization. A difference in color of the foliage, however, was not noticeable until the ninth year and no increase in yield has yet occurred. The clean culture plot did not average as great an annual twig growth in the second four-year period of the experiment as in the first four-year period but in the ninth year was 58 per cent greater than the sod plot. The yields, as yet, have not been so affected in the clean culture plot.

3. The daily growth was more or less erratic each season, *i. e.*, not following consistently any external factor under observation.

The growth curve follows the air temperature more closely, however, than any other external factor recorded. There is no close correlation between the humidity curve and growth curve. It is not possible to control the separate factors under field conditions. These conclusions are based on 43,000 measurements during three seasons.

4. The growth is much more readily affected by external factors in the early period of its growth than when it is approaching the resting period.

5. The grand period of growth in this orchard was a period of about 25 days (3 years considered).

SOIL TEMPERATURE.

Among the external factors that influence the growth of our trees, the soil temperature doubtless plays a part. Hence we may inquire what the differences in temperature would be between plots treated in various ways in the orchard and whether they are very marked in character. Since bacteria and soil flora have certain optima of temperature at which they best thrive and since these agencies in turn are responsible in part for growth the question at issue assumes some importance.

Although it has not been possible to make extensive observations of the soil temperature factor, yet by the use of accurate instruments a number of readings were made which give us some index of the temperature conditions which obtain under the various soil treatments. The apparatus used was a set of Resistance Thermometers, manufactured by Leeds and Northrup Co., Philadelphia, Pa. A bulb was placed eight inches below the surface of the soil in Plots 1, 4, 5, 7 and 9; and one at three feet below the surface in Plots 1, 4 and 7, in close proximity to the ones near the surface.

The readings were made each day at 2 o'clock p. m. except Sundays, and an occasional day in addition. While we do not know what the maximum temperature was we assume that the readings at 2 o'clock would not be far from giving the maximum for that day.

From the investigations reported in Tech. Bulletin No. 26, Michigan Agricultural Experiment Station, it is seen that a study of the temperature of soils is a complicated matter. The soil is affected by several external factors and also by intrinsic factors. The temperature records here given, however, do not deal with the causes for or factors which have brought about the temperatures recorded but rather are offered as a statement of what temperatures obtained in the soil of the various cultural plots. Since air temperature is the most potent factor in determining the soil temperature it is herein used for comparison.

RELATION OF AIR AND SOIL TEMPERATURES.

The soil is probably affected to a greater extent by the temperature of the air than by any other external factor, and the nature or amount of soil covering seems to be the greatest factor in influencing the degree to which the soil will respond to the changes in the air temperatures. From Chart No. 1 it can be seen that the temperature of the soil changes in the same direction as the air temperature but does not respond immediately and can be seen on the day following rather than on the same day. This follows pretty consistently across the chart. This is brought out more in detail below.

EFFECT OF CULTURAL TREATMENTS ON SOIL TEMPERATURE.

By examining Table No. 1 and Chart No. 1 it will be seen that there is not a great variation in the temperature of the various plots at any one time. While there is a little difference in the soil at the two ends of the orchard it can be assumed that that fact would not account for much variation in temperature, for according to Bouyoucos, there is little difference throughout the summer between the various soil types and the variation in soil type is much less marked in this orchard than in the kinds with which he worked.

The plots under observation have been treated as follows since the spring of 1908:

Plot 1. Permanently in sod.
Plot 4. Clean Cultivation each year (no cover crop).
Plot 5. Cultivation with a cover crop.
Plot 7. Same as Plot 5, but an application of complete fertilizer is applied each spring.
Plot 9. Same as Plot 7, except the complete fertilizer in this case is higher in nitrogen than in Plot 7.

The first readings began April 13, 1916, and were more or less intermittent until the middle of May from which time they were taken daily except as noted above. From April 13 until June 7, Plot 1 (the sod plot) runs lowest in temperature while Plots 4 and 5 are highest. It might be stated that the cover crop on Plot 5 was very poor in 1916, due to a very rainy fall previous and the crop practically died out, the other plots were not so affected because the land is slightly more ridged and hence has better surface drainage, also Plots 7 and 9 had a much heavier cover crop due to the fertilizer treatments. The average of the readings of the various plots for the season are shown below:

TABLE No. 1.

Average Soil Temperatures—Woodman Orchard.

1916.

At 8 inches.

	Plots.				
	1.	4.	5.	7.	9.
April	38.3	43.0	45.8	42.9	42.5
May	52.3	55.5	56.3	57.8	54.7
June	59.3	61.1	63.1	60.4	57.9
July	66.8	69.7	69.0	68.6	65.7
August	66.6	69.6	68.0	67.2	65.2
September	61.9	64.5	62.3	61.6	61.1
Average	57.5	60.5	60.7	59.7	57.8

Thus for the month of April the sod plot is the coldest and those having a heavy mat of cover crops (Plots 7 and 9) are next lowest, while the clean tilled plot and Plot 5 are highest.

In May the sod plot still remains coldest, averaging 52.30° and Plot 9 next 54.7° while Plot 7 is warmest 57.8°. But in June the coldest plot shifts to Plot 9 which had the heaviest cover of any of the plots, being fertilized with a higher per cent of nitrogen, and it remains the lowest throughout the season even when cultivated. (The reason for the latter does not seem evident.)

TABLE NO. 2.

Average Soil Temperatures—Woodman Orchard.

1916.

At 3 feet.

	Plots.		
	1.	4.	7.
May	46.87	48.00	49.62
June	50.77	51.51	52.28
July	57.26	58.26	59.60
August	60.07	61.62	62.24
September	59.50	61.14	60.14
Average	54.89	56.11	56.78

By referring to the curves on Chart No. 1, it will be seen that the sod plot started at 11 degrees colder than the clean culture plot, but with an occasional exception the difference was not more than 2 to 5 degrees, until early in June when they ran much the same for a fortnight. Toward the end of June (22d)* the clean culture plot (Plot 4) was plowed and it again ran higher throughout the season than the sod plot as no cover crop is grown on Plot 4. It is noticeable from the curves that Plot 4 responds in a much greater degree to the fluctuations of the air temperature than the sod plot, making a difference of 9° on July 13. The greatest average difference in temperature occurs in April, 4.7°, and the lowest in June, 1.8°. For May, 3.2°, for July, 2.9°, for August, 3.0°, for September 2.6°.

It may be that the low temperature in Plot 9 during the period of cultivation may in part be due to its higher moisture content. A greater evaporation from the soil would cause a lower degree of temperature and this plot ranks a little higher in moisture than any of the five plots under discussion. Plot 4 which is highest in temperature in July, August and September is lowest in mois-

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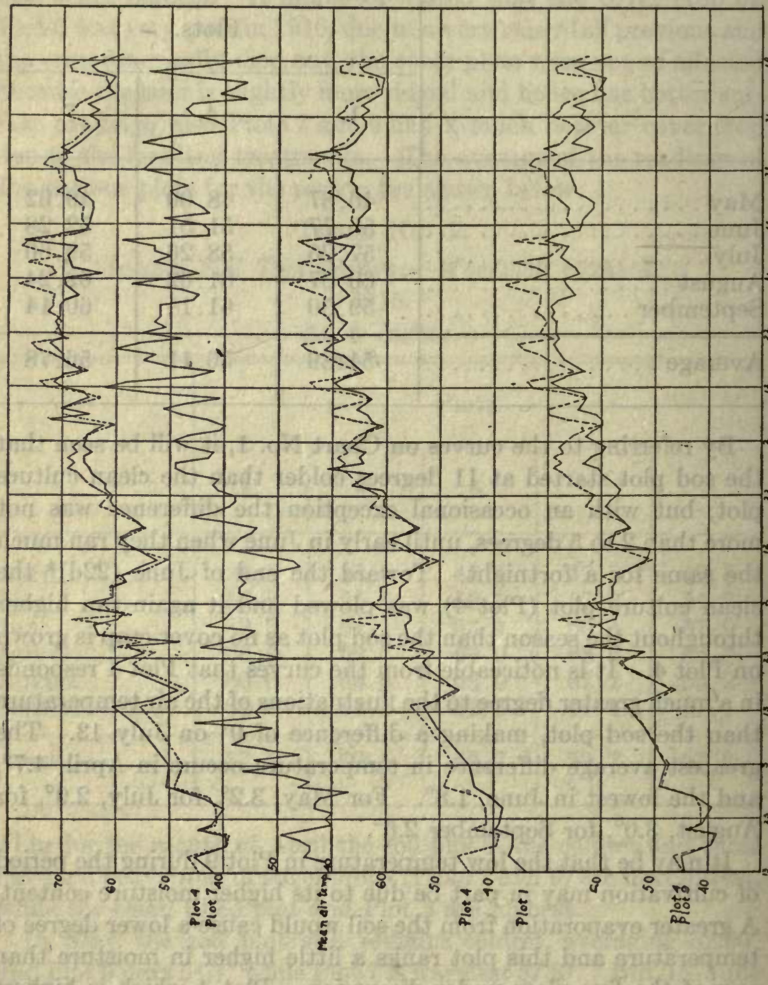
*This date was very late. Owing to wet weather it was impossible to get on this soil earlier.

CHART NO. 1.

Soil Temperature—1916.



ture, but the fact that it has no covering is probably the most important cause. This relationship is seen in Table No. 3.

TABLE NO. 3.

Average Soil Temperatures and Average Per Cent Moisture Per Plot—Woodman Orchard.

1916.

At 8 inches.

	Plots.									
	1.		4.		5.		7.		9.	
	Mois.	Tem.	Mois.	Tem.	Mois.	Tem.	Mois.	Tem.	Mois.	Tem.
April	.....	38.3	.....	43.0	.....	45.8	.....	42.9	.....	42.5
May	12.4	52.3	11.4	55.5	16.8	56.3	22.0	57.8	24.2	54.7
June	24.6	59.3	17.8	61.1	23.6	63.1	24.7	60.4	25.5	57.9
July	19.2	66.8	17.1	69.7	13.9	69.0	24.8	68.6	24.9	65.7
Aug.	24.0	66.6	16.6	69.6	19.9	68.0	22.6	67.2	22.8	65.2
Sept.	18.7	61.9	15.2	64.5	21.3	62.3	22.5	61.6	21.2	61.1
Average	19.7	57.5	15.6	60.5	19.1	60.7	23.5	59.7	23.7	57.8

In the subsoil which is recorded at 3 feet below the surface we find each month that the sod plot (No. 1) is lower than the other two plots recorded (Plots 4 and 7), with an average for the season of 54.89°. Plot 7 is the highest each month, except in September, which is not true with the surface soil. However, there is only a slight difference between Plots 4 and 7 in this regard, and the average difference for the season is only .67 of one degree. See Table No. 2.

The soil moisture in this case shows the highest per cent obtains where the temperature is highest, and the lowest temperature where the moisture is intermediate. In other words, no correlation seems to exist between these two factors in the subsoil, where of course no evaporation is taking place. For complete data on the soil temperature see Table No. 5.

The same general conclusions can be drawn from the actual depth of freezing as were drawn from the temperature of the surface soils. On March 6, 1916, the soil was frozen as deep, probably, as at any time during winter and observations were made on the depth of freezing in each plot which gave the following figures:

TABLE NO. 4.

Depth of Freezing—Lower Woodman Orchard.

March 6, 1916.

Plot No.	Depth in Inches.
1	12
2	18
3	13
4	16
5	15
6	12
7	10
8	8
9	7
10	7

Chart No. 2 shows this in a graphic way and shows Plots 6 to 10 are frozen several inches less than the others and it is true that there was a much heavier covering on these plots than on the first five. Plot 2 seems to be an exception and it would not appear just why it should be frozen more deeply than any of the others. No actual temperature records were made during the winter of 1915–1916 but the depth of freezing shows roughly what would have been recorded. The orchard was then all plowed except Plots 1 and 3 in the fall of 1916 so that there was no covering to protect the ground as in the previous winter, and the temperatures ran much the same in the various plots.

CHART NO. 2.

Depth of Freezing in Plots at Woodman Orchard, March 6, 1916.

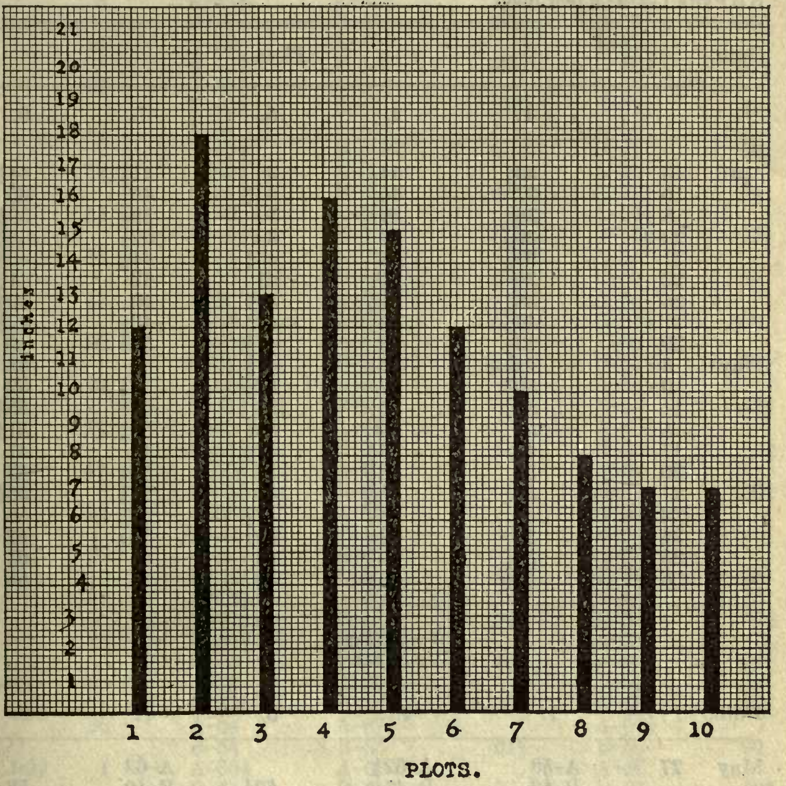


TABLE NO. 5.

Soil Temperature Records—Woodman Orchard.

1916.

Temperature apparatus installed April 13, 1916.

A = Plots 1–4–5–7–9; 8 inches deep.
B = Plots 1–4–7; 3 feet deep.

Date.		Plots.				
		1.	4.	5.	7.	9.
April	13	33¾	44½	36	41½	44½
	16	37	46½	43¾	45¼	45
	18	36½	39½	39	39½	39½
	20	36½	39	39	39½	38½
	21	39¾	44	43¼	44½	43½
	22	39	41¼	41	42	41¼
	25	38¼	41½	39½	40	39¼
	27	40½	42½	42¼	43½	42½
	29	43½	49	47½	50½	49
May	3	44½	47½	47½	50	48
	10	50½	52	52¾	55¼	52
	14	53	55¼	58	60¼	55½
	15	51	50	52½	53¼	51½
	17	47	46½	47½	48	47
	20	51	53½	54	55½	53
	21	52¼	55¾	56	60½	55½
	22	53	56¾	57½	59½	56
	24	51	52½	52¾	54½	52
	25	55½	59½	64	68	63
	26	53½	55½	58	58	55

A—Surface
B—3 feet

Date.		1.	4.	5.	7.	9.
May	27	A–56	A–62½		A–63	
		B–46	B–47	62½	B–49	58
	29	A–56¼	A–61		A–64	
		B–47	B–48	62¾	B–49½	60½
	30	A–55½	A–68		A–59¾	
		B–47¼	B–48½	60	B–50	57¼
	31	A–55½	A–57		A–58½	
		B–47¼	B–48½	59	B–50	57½
June	1	A–58	A–61¼		A–64½	
		B–48	B–49½	66½	B–50½	60½
	2	A–58¼	A–62½		A–66	
		B–48½	B–49½	67¼	B–51	61
	3	A–57½	A–61		A–60½	
		B–49½	B–50	63	B–51½	58
	5	A–57½	A–61		A–60½	
		B–49½	B–50	63	B–51½	58

Date.		1.	4.	5.	7.	9.
June	6	A–56	A–58		A–58	
		B–49	B–50	59	B–51½	57½
	7	A–57½	A–60		A–59	
		B–50¼	B–50½	61	B–51½	57¼
	8	A–55½	A–55¼		A–56¾	
		B–50	B–51	57½	B–52	55½
	10	A–52	A–50½		A–52¼	
		B–49¾	B–50½	52	B–52	51¼
	12	A–55¾	A–56¾		A–56	
		B–49½	B–50	57¾	B–51¼	51
	13	A–57	A–59½		A–58	
		B–49½	B–50	61	B–51	58
	14	A–59¼	A–59		A–59	
		B–51¼	B–50	63	B–51¼	59
	15	A–56	A–56½		A–57¼	
		B–49½	B–50½	58¼	B–51½	57½
	16	A–54	A–54¾		A–55	
		B–50	B–51	56½	B–52	55
	17	A–56	A–56		A–56	
		B–51	B–50½	57	B–51½	56
	20	A–60½	A–63		A–60½	
		B–51	B–52	64	B–52½	59¼
	21	A–60½	A–62		A–61	
		B–51¼	B–52	65½	B–53	58½
	22	A–60	A–61¼		A–60¾	
		B–51½	B–52½	65	B–53	57¼
	23	A–60¾	A–63¼		A–62	
		B–51¾	B–53	66	B–53	56¾
	24	A–66¼	A–65		A–62	
		B–52	B–53	66½	B–53½	57½
	26	A–62¾	A–67		A–64½	
		B–52½	B–53¾	68½	B–54¼	60
	27	A–70¾	A–69		A–65	
		B–52¾	B–53½	69½	B–54½	60¾
	28	A–64¼	A–67¾		A–66	
		B–53	B–54	70	B–55	63½
	29	A–65	A–69		A–66	
		B–53½	B–54½	70	B–55	62
	30	A–64	A–67¼		A–64½	
		B–54	B–55	67½	B–56	60
July	1	A–66½	A–68		A–66	
		B–54	B–55½	70	B–56	59½
	3	A–64	A–65½		A–65½	
		B–54¼	B–55½	68	B–56	63
	4	A–63½	A–63¼		A–64	
		B–55	B–55½	65	B–56½	62
	5	A–61½	A–60½		A–62¼	
		B–55	B–56	63	B–57	60
	6	A–63	A–66¼		A–72	
		B–55	B–56	66	B–57	60
	7	A–63½	A–70		A–65	
		B–55	A–56	67¼	B–57	61
	8	A–65½	A–70		A–70	
		B–55	B–56	70	B–57¼	64½
	10	A–63	A–63		A–65	
		B–56	B–56	66¼	B–57½	63

Date.		1.	4.	5.	7.	9.
July	11	A-64½	A-66½		A-66	
		B-56	B-58	67	B-57	63½
	12	A-68¼	A-73		A-70	
		B-56	B-57	72	B-58	67½
	13	A-69½	A-74		A-71½	
		B-56¼	B-58	73½	B-58½	69¼
	14	A-67½	A-68¾		A-70	
		B-57	B-58½	70½	B-59	67
	15	A-64½	A-65¼		A-66½	
		B-56¾	B-58½	66½	B-59½	63¼
	17	A-67	A-70		A-70	
		B-57½	B-58¼	70	B-69½	67
	18	A-68	A-71½		A-70	
		B-57	B-58¼	71	B-59¾	67¾
	19	A-71½	A-74¾		A-71	
		B-57½	B-59	72¼	B-60	68½
	20	A-70¼	A-75¾		A-72¼	
		B-59	B-59	73¼	B-60	69
	21	A-68	A-69		A-70	
		B-58	B-58½	70	B-59½	68
	22	A-69	A-71½			
		B-57	B-59¾	70¼		68½
	24	A-67½	A-70¼		A-71¼	
		B-59½	B-60½	69¾	B-61½	68½
	25	A-69	A-71		A-70½	
		B-59	B-60	71	B-62	69¼
	26	A-69¼	A-72½		A-70½	
		B-60	B-60	70	B-62	69
	27	A-70	A-71¾		A-70½	
		B-62	B-61	70	B-61¼	69¾
	28	A-68½	A-71¾		A-69¾	
		B-60½	B-61½	69¼	B-62¾	68¼
	29	A-67	A-71½		A-67	
		B-60	B-61½	66½	B-62½	65
	31	A-69	A-78		A-69¾	
		B-60½	B-61	67¾	B-63	66¾
August	1	A-69	A-73¾		A-69½	
		B-60	B-60½	69	B-62	67
	2	A-66½	A-70¼		A-62¾	
		B-60	B-61	65½	B-62½	64¼
	3	A-67¼	A-72		A-68¼	
		B-59½	B-61½	68¼	B-62	65
	4	A-68	A-76¼		A-68½	
		B-59¾	B-61	68½	B-62	66¼
	5	A-67½	A-70¼		A-69	
		B-60	B-61½	68½	B-62	67¾
	7	A-66¼	A-67¾		A-67½	
		B-60	B-62	66½	B-62	66¼
	8	A-71½	A-76¼		A-77	
		B-60½	B-62½	72½	B-62¼	70¾
	9	A-67½	A-68¼		A-70¼	
		B-60	B-60	68¼	B-62½	68½
	10	A-65¼	A-65		A-65¾	
		B-60¼	B-62½	64¼	B-62½	64¼
	11	A-65½	A-66		A-65¼	
		B-60	B-62	65½	B-63¼	63¾

Date.	1.	4.	5.	7.	8.
August 12	A–65¼	A–66¾		A–65	
	B–60	B–61½	65¾	B–63	63¾
14	A–63¼	A–66¼		A–64½	
	B–60	B–62½	66¼	B–62	61¾
15	A–63¼	A–67¼		A–64½	
	B–59¾	B–61	66¾	B–61½	61¾
16	A–64¼	A–68½		A–65½	
	B–59¾	B–60½	68	B–61½	63
17	A–65¾	A–71		A–67¼	
	B–59¼	B–60¾	70	B–61¼	65
18	A–65¾	A–69½		A–65	
	B–59½	B–60¾	68¾	B–61¼	65
19	A–66¾	A–70½		A–67¾	
	B–60	B–60½	69¾	B–61¾	65½
21	A–66¼	A–71		A–68	
	B–59¾	B–61¼	70½	B–62	66¼
22	A–68¾	A–73¾		A–70½	
	B–60¼	B–61¼	72¼	B–62¼	69
23	A–68½	A–72¾		A–69¼	
	B–60½	B–62¼	71	B–62¾	68
24	A–74½	A–68½		A–69½	
	B–60½	B–62¼	69¾	B–62½	68½
25	A–67¾	A–70½		A–68¼	
	B–61	B–62¾	69½	B–63	62
26	A–66	A–68		A–67	
	B–60¾	B–62¾	67½	B–63	65¾
29	A–64	A–65¼		A–63½	
	B–60½	B–62½	64½	B–62¾	61½
30	A–64	A–66½		A–63½	
	B–60¼	B–61½	65	B–62	62½
31	A–64¾	A–69¼		A–65	
	B–60	B–61¾	67¼	B–62¾	64
Sept. 1	A–63¼	A–68		A–63½	
	B–60	B–62½	66	B–61½	63¼
2	A–64¾	A–67½		A–65½	
	B–59¾	B–62¾	65½	B–61¼	65¼
4	A–61	A–63½		A–60½	
	B–60	B–62	61¼	B–60½	59½
5	A–61	A–61½		A–62	
	B–59¾	B–62	61½	B–60½	60¾
7	A–60½	A–62		A–60¼	
	B–59	B–60½	60	B–60	59½
8	A–64¼	A–68½		A–63¾	
	B–59	B–60½	65	B–59½	63¼
9	A–65	A–68¾		A–64¾	
	B–58¾	B–60¾	66¼	B–59¾	65
11	A–60	A–62½		A–59	
	B–59	B–60¼	59½	B–60	58½
20	A–57½	A–58¾		A–55½	
	B–58¼	B–59	55½	B–58¼	55

EFFECT OF CULTURAL TREATMENTS AND FERTILIZERS ON GROWTH.

It is now pretty generally accepted by investigators in pomology in this country that growth and yield of apple trees are not antagonistic but rather that they accompany one another, within a reasonable degree. This has been the experience in the Woodman Orchard, that is, for an average of eight years the poorest growing trees are the poorest yielders, the plot that ranks next lowest in growth also ranks next lowest in yield, the third poorest grower also ranks third poorest in yield, while in the remainder of the plots the correlation does not hold, although the differences in growth in the remaining plots is not so marked. In general the best bearing trees are also good growing trees.

But what brings about a stimulation to growth in the orchard? It is well known by every orchardist that cultivation will make a marked effect in the growth and general healthful appearance of the trees often the first season without previous preparation on the part of the tree. It is also well known that nitrogenous fertilizers, especially the more readily available forms, such as nitrate of soda, will bring about an increased growth of the trees. And the converse of this treatment, *i. e.*, growing trees in sod land will usually result in a poor growth especially on mature trees. Of course there must be sufficient moisture present, also, in addition to the other factors for growth.

METHODS OF RECORDING GROWTH.

Since the cultivated orchard under consideration has been slow to respond to fertilizer treatments in its *yield* it has been of interest to watch the effect of the treatments on the growth of the trees.

It has been a question in the mind of the writer for some time as to what particular measurement best represented the index of the annual growth produced each year by an apple tree. It has been our practice since 1909 to measure the length of the terminal growth of the main branches, selecting those representing the normal of the tree, so far as the observer could determine. Twenty such twigs are measured on each tree annually and averaged, and then all the trees for the plot are averaged, which figure is taken as an approximate index of the growth of the trees under the particular soil treatment of that plot. This method is fairly good but has some objections which make it somewhat faulty. In the first place there may be a heavy water sprout growth on the tree which must be eliminated, and also there is great variation in the length of what might be considered "normal growth," and the relatively small number of twigs which it is physically possible to measure in a large orchard is quite small, so that the final figure arrived at is not entirely satisfactory. There is also the personal element which enters in when different men make the observations from year to year that may fail to make the figures exactly comparable. Another method for attempting to secure the index of growth is to caliper the trees at a given distance from the ground and take the diameter growth as the index. This would seem to be more accurate in many ways and this method has also been employed since 1913, and both data are given below in Tables No. 6, 7 and 8.

SCHEDULE OF TREATMENT OF PLOTS.*

Crimson clover is used as a cover crop in every case. Seed is sown July 10 at the rate of 20 pounds per plot. In seeding plots 2 and 3 the following mixture is used:

10 pounds	timothy
10 pounds	red clover
5 pounds	white Dutch clover.

Plot 1. Sod. To remain permanently in sod. Grass to be mown when inconveniently long and allowed to remain on the ground. No fertilizer to be applied.

Plot 2. Cultivated the odd year, cover crop sown July 10, seeded the even. No fertilizer is applied.

Plot 3. Cultivated the even year, cover crop sown July 10, seeded the odd. No fertilizer is applied.

Plot 4. Clean cultivation. This plot is plowed every spring and cultivated every two weeks until September 1. No cover crop is sown and no fertilizer is applied.

Plot 5. Cultivation and cover crop. This is plowed every spring and cultivated every two weeks. A cover crop consisting of 20 pounds of crimson clover is then sown. No fertilizer is applied.

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* For more extensive description of orchard and soil, see Tech. Bull. No. 9.

Plot 6. Cultivation and cover crop, with the following complete fertilizer per tree:

2 pounds nitrate of soda
4 pounds sulphate of potash
7 pounds basic slag.

Plot 7. Cultivation and cover crop, with the following complete fertilizer per tree:

2 pounds nitrate of soda
4 pounds sulphate of potash
8½ pounds acid phosphate.

Plot 8. Excess phosphorus. Cultivation and cover crop, with the following complete fertilizer per tree:

2 pounds nitrate of soda
4 pounds sulphate of potash
17 pounds acid phosphate.

Plot 9. Excess nitrogen. Cultivation and cover crop, with the following complete fertilizer per tree:

6 pounds nitrate of soda
4 pounds sulphate of potash
8½ pounds acid phosphate.

Plot 10. Excess potassium. Cultivation and cover crop, with the following complete fertilizer per tree:

2 pounds nitrate of soda
10 pounds sulphate of potash
8½ pounds acid phosphate.

EXAMINATION OF DATA.

Upon examination of this table it will be seen that the effect of cultivation (which was begun 1908) was at once seen in the growth of the twigs, Plots 1 and 2 not being tilled the first year.

As would be expected, the trees in the sod plot (Plot 1) have made about the same growth from year to year, and what slight differences occur can probably be accredited to weather conditions. These trees have averaged from a little more than four inches to nearly six and a half inches of growth a year, and the average of the eight years, 1909–1916, is 4.81 inches, which is an unsatisfactory growth and not sufficient to keep the trees in a productive

TABLE NO. 6.

Average Annual Twig Growth per Tree in Plots—Woodman Orchard.

Length in Inches.

Year	Plots.									
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
1908.......	No Records.									
1909.......	4.59	4.08	5.34	6.29	8.31	8.33	7.08	6.85	8.02	7.24
1910.......	4.15	6.78	6.95	8.79	10.19	11.00	9.85	10.14	10.93	9.85
1911.......	3.21	6.69	7.55	8.43	8.19	9.13	7.68	7.94	8.20	7.87
1912.......	4.79	5.93	7.46	8.43	8.92	9.72	8.64	8.55	9.26	8.93
1913.......	5.76	6.23	8.78	9.03	9.03	9.86	10.13	9.47	8.65	9.65
1914.......	4.7	4.7	3.98	4.9	6.9	8.92	10.3	10.44	11.57	10.43
1915.......	6.4	5.1	9.65	7.18	10.3	9.8	11.0	11.9	11.9	12.1
1916.......	4.9	5.6	7.4	7.7	7.9	9.4	10.6	9.9	9.7	10.7

state. However, during the second four years of the experiment the growth of this plot has averaged a little higher than the first four years which seems high when expressed on a percentage basis.

Plot 4, which is tilled each year throughout the season but has no cover crop and receives no fertilizer has fallen off in the amount of annual growth produced. It has always averaged considerably more growth than the sod plot and with the exception of one instance has averaged considerably more than the two plots (Plots 2 and 3) which are tilled every other year, and for the eight year period averages 7.59 inches or 58 per cent greater than Plot 1. But it is worthy of notice that the second four-year period averages less growth than the first four-year period, seeming to indicate that the soil treatment was scarcely sufficient to maintain the trees in an optimum state of growth, although the yield has been maintained.

Plot 5 which has clean cultivation until July 10 when it is seeded to a cover crop of crimson clover and latterly with an admixture of winter vetch has averaged 8.72 inches for the eight years showing a little superiority over the previous plot, and more than 80 per cent superiority over sod. As has been pointed out in previous bulletins, it is a little surprising that this superior

CHART NO. 3.

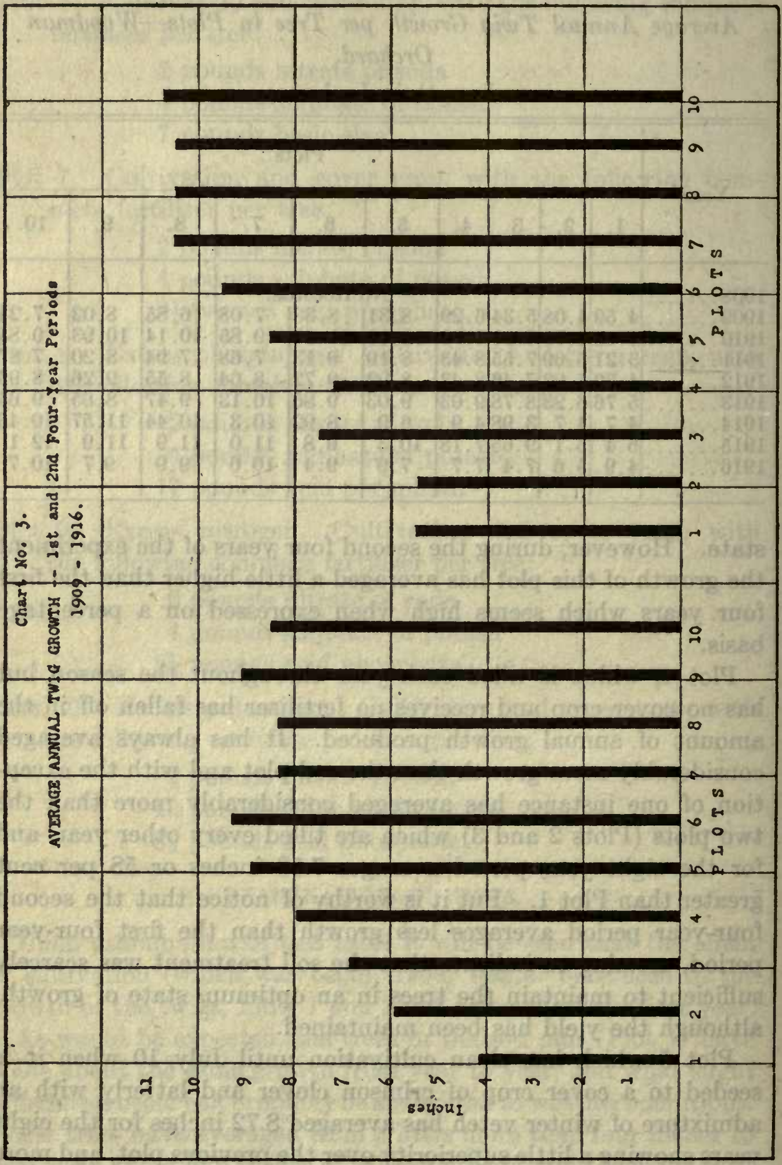


Chart No. 3.
AVERAGE ANNUAL TWIG GROWTH -- 1st and 2nd Four-Year Periods
1909 - 1916.
Inches
1
2
3
4
5
6
7
8
9
10
11
PLOTS
1
2
3
4
5
6
7
8
9
10
PLOTS
1
2
3
4
5
6
7
8
9
10

soil treatment has not given an increase in yield over the previous plot, especially when the growth is in its favor. The growth in this plot has scarcely held its own during the second four-year period of the experiment, which is doubtless significant in the face of the subsequent plots, which under fertilization, have all increased in the second four-year period. However it must still be stated that after nine years the orchard has not paid in dollars and cents for the fertilizers which have been applied.

TABLE NO. 7.

Average Twig Growth—Woodman Orchard.

1909–1916.

Inches.

	Plots.									
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
First 4 Years...	4.18	5.87	6.82	7.98	8.90	9.29	8.31	8.37	9.10	8.47
Second 4 Years..	5.44	5.41	7.45	7.20	8.53	9.49	10.51	10.43	10.45	10.72
Increase.......	30%	−8%	9%	−10%	−4%	2%	26%	24%	14%	26%
Eight Year Average..........	4.81	5.01	7.14	7.59	8.72	9.52	9.53	9.39	9.78	9.59

In the subsequent plots—Nos. 6, 7, 8, 9 and 10, we see that all have more than maintained their growth since the early years of the experiment and most of them have gained considerably under the treatments they have received. This is also true of the cover crops on these plots, but has been especially noticeable the past two years (1915–1916). Therefore we can summarize the effect of the fertilizer treatments on these plots by saying that they remained about the same as the one receiving good culture including a cover crop (Plot 5) but without fertilization, for the first six years of the experiment but since that time the growth has been noticeably greater, and in the ninth year (1916) the average of all the fertilized plots was 26 per cent greater than Plot 5. Graphs showing the average growth during the first and second four-year periods are shown in Charts Nos. 3. and 5. Possibly the most striking feature of these charts is the gain made by the excess potash plot which now slightly leads the excess nitrogen plot, also the falling off of Plot 4, and to a less degree, Plot 5.

CHART NO. 4.

Average Twig Growth—Woodman Orchard, 8 Year Average.

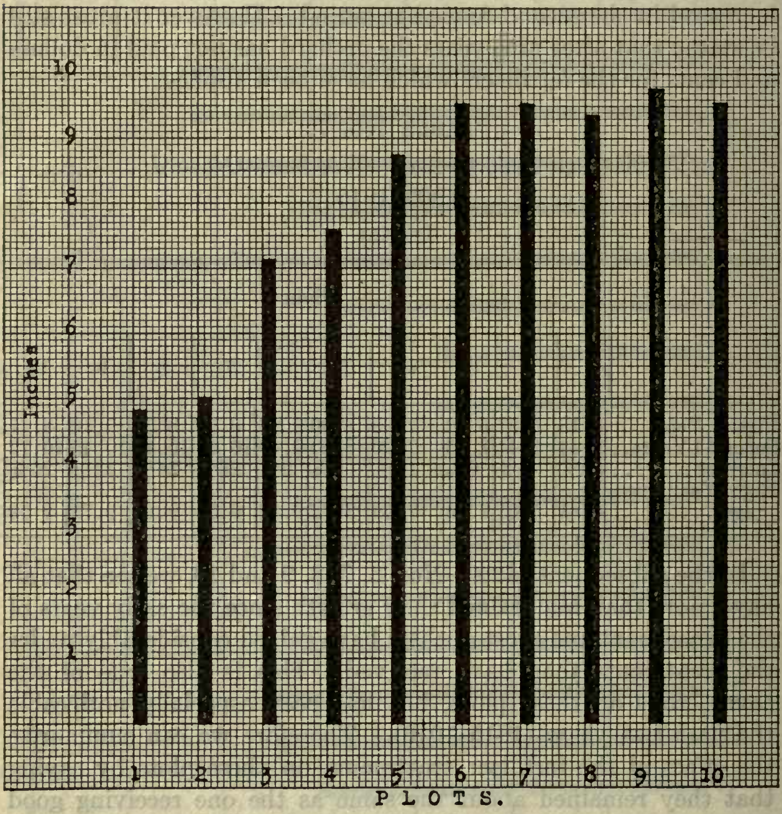
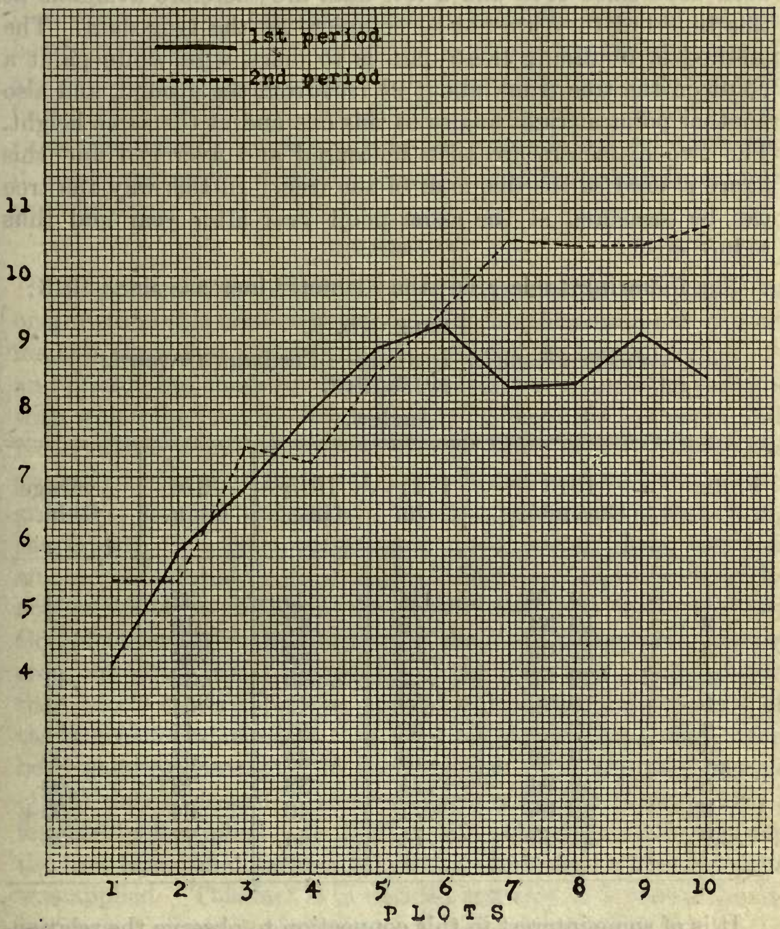


CHART NO. 5.

Average Twig Growth—First 4 Years and Second 4 Years.



DIAMETER DATA.

As stated above it would seem to be desirable to take the diameter increase of the trees as a better index of the growth than is represented by measuring a limited number of twigs. This has been done since 1913 and a few data are therefore available at this time but they are not so complete as the twig data. The method of obtaining these data is to mark with white paint a point on the tree trunk about 2½ feet from the ground, and also another point at right angles to this one and at the same height. The two diameters are then measured and averaged and this figure is used as the diameter of the tree. In this way the tree can be measured at the same point year after year and thus reduce error.

The following table gives the diameter increase since 1913:

TABLE No. 8.
Average Diameter Increase—Woodman Orchard.
1913–1916.
Inches.

Plots.	1913 Diameter.	1914 Gain.	1915 Gain.	1916 Gain.	Average Gain.
1	9.78	.38	.25	.32	.31
2	10.33	.45	.37	.19	.33
3	11.05	.48	.42	.28	.39
4	10.59	.42	.45	.35	.41
5	10.80	.59	.41	.54	.51
6	10.55	.63	.51	.47	.54
7	10.59	.73	.44	.62	.60
8	10.94	.74	.33	.73	.60
9	10.66	.71	.46	.64	.60+
10	11.18	.74	.44	.77	.68

It is of some interest in this connection to observe the relationship which exists between the two sets of data, *i. e.*, the average annual twig growth and the average annual diameter increase. Chart No. 6, shows a graph giving the twig increase and the diameter increase for an average of 3 years (1914, 1915, 1916) and it fairly represents what data we have obtained in this orchard. The curves do not follow exactly and yet they show about the same general form. Which one would come nearest to a correct index of growth would be difficult to say, but the writer is of the opinion that a majority of workers would prefer the caliper measurements. However, he is inclined to the opinion that when the twig measurements are carefully made on mature bearing trees which are under the same type of treatment annually and without radical changes in pruning that the twig data are fairly representative of the growth of the tree. Nevertheless, since the diameter measurements are so much simpler to make, it might seem more desirable to adopt that procedure in similar experiments.

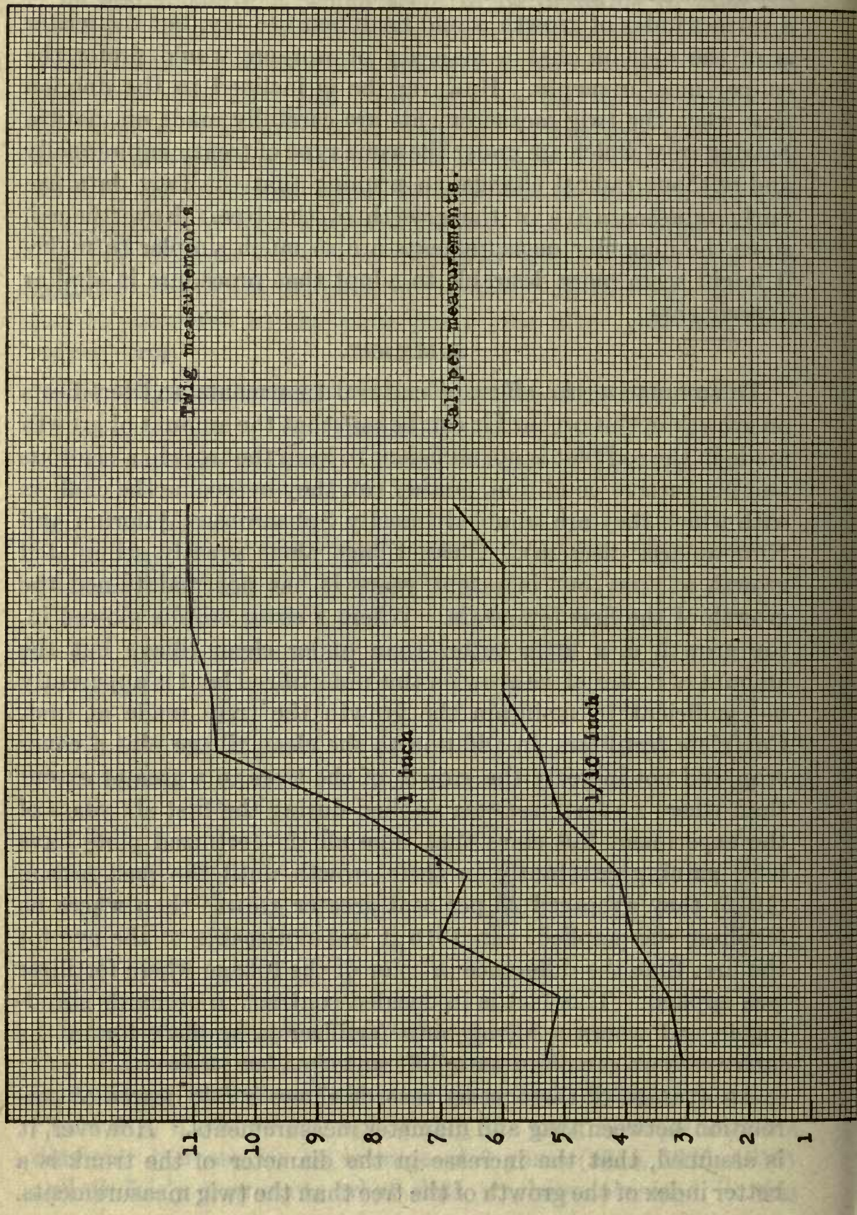
SUMMARY.

To summarize the effect of cultural treatments and fertilizers on growth in this orchard it can be said that the amount of growth made in the sod plot is not sufficient to keep the trees in a vigorous and productive condition, neither can they overcome the cankers with which they are troubled (mostly Sphaeropsis Malorum and Nummularia discreta). Clean tillage alone greatly stimulated growth at first but in recent years it has not maintained the growth of the first few years. Where a cover crop is plowed in, the growth is a little better than under clean tillage but the amount of material we grow on this unfertilized land is apparently not sufficient to maintain the growth the trees made at first. Complete fertilizers, in addition to the clean tillage plus a cover crop, did not increase the growth of the trees to a greater extent than where no fertilizer was applied during the first six years of the experiment but since that time all the fertilized plots have been gaining constantly in their growth until the past season (1916) they averaged 26 per cent greater growth than where no fertilizer was applied. In 1916 it was noticeable to the eye for the first time the difference in color of the foliage where fertilizer was applied. This fact is in decided contrast to orchards standing in sod where a nitrogenous fertilizer is applied, for in the latter case we can often see a difference in a few weeks.

An average of three years records shows a fair degree of correlation between twig and diameter measurements. However, it is assumed, that the increase in the diameter of the trunk is a better index of the growth of the tree than the twig measurements.

CHART NO. 6.

Comparison of 3 Year Average of Annual Twig Growth and the Diameter Growth for Same Period—1914–1916.



DAILY GROWTH.

In addition to recording the annual growth made by the trees in the various plots, we have also attempted to measure the daily growth of the trees for three seasons, 1913, 1914 and 1916. The intention was to try and obtain an index of the vigor of the trees under different treatments, but since vigor is difficult to define the results have not been satisfactory and no effort has been made to utilize the data in that way. However, these data may be worth recording since they are taken on a rather large scale and represent three seasons which differed, especially as to rainfall. The data represent gross field observations and can scarcely be compared with the minutely accurate growth records to be found in botanical literature where auxanometers are employed, which would have been impossible in this case.

During the season of 1913, 8 twigs from each plot or 80 twigs in the orchard were measured daily; in 1914, 40 twigs per plot or 400 twigs were measured; in 1916, 30 twigs per plot or 300 twigs were measured. This makes a total of 43,000 measurements during three seasons on which this work is based. The total number of 16ths that all these twigs grew in any plot in any day is shown in Tables Nos. 9, 10 and 11. The plots are then averaged and the graphs shown in Charts Nos. 7, 8 and 9 show the average results of the orchard for each day.

It will be seen that the amount of growth from day to day varies considerably but these differences are less marked the nearer the trees approach their resting period. We have attempted to learn what external factor affected this growth to the greatest degree, but of the factors under observation none correlate exactly with the growth behavior. The growth seems to be more or less erratic, behaving at times in the opposite way from that expected. However, they follow somewhat closely the curves of temperature but doubtless many factors so combine to affect growth that no one factor can be clearly separated as the governing one when the plants are not under controlled conditions. These factors are exceedingly complex and preclude as definite deductions as might have been hoped for. Neither the curve of humidity or rainfall when considered apart from other factors will correlate with the growth behavior. In Chart No. 9, which shows the growth increments for 1916, it will be seen that in practically every case where the growth is checked the temperature dropped noticeably and vice versa, but even here we can see an occasional case which is exactly opposite. The maximum and minimum temperatures are given above and below the broken line, respectively, the latter representing the mean temperature. The broken line above is the mean humidity curve. The instruments recording these data are located in the orchard.

By examining the data in Tables Nos. 9, 10 and 11, it will be seen that the plots behave differently, depending somewhat upon the type of treatment they receive. In Table No. 11 (1916) it will be observed that Plot 1 shows cessation of growth first while Plot 2 soon follows, neither of these plots were cultivated that season but Plot 2 is in a better condition for growth than Plot 1 since it is tilled every other year while the latter plot is continuously in sod. Plot 3 next ceases to grow followed by Plot 4, while Plots 7, 8, 9 and 10 grow up until after July 17th. The rainfall doubtless explains this since the seasons 1913 and 1914 both being dry in July they ceased to grow at a much earlier date. Of these fertilized plots which also run higher in moisture, Plot 9 showed the greatest growth up until the last and this one receives a heavier application of nitrogen fertilizer than the others, which may explain it.

In Table No. 10 (1914) it is striking to notice how Plot 4 continued to grow after the plots on either side of it had ceased growth. This plot is cultivated until September 1, while in the others the cultivation is stopped on July 10 when they are seeded to a cover crop.

GRAND PERIOD OF GROWTH.

It will be seen from the charts that the grand period of growth in this orchard lasts about 25 days, beginning somewhere between the 20th and 25th of May and practically ceasing the latter part of June, depending on the treatment of the plot and the season. "Grand period" as here used refers to the period in which practically all the growth is made, but does not include the second growth which under certain conditions may continue the period somewhat.

CHART NO. 7.

Daily Twig Growth—1913. Average of all Plots in 1/16 Inches.

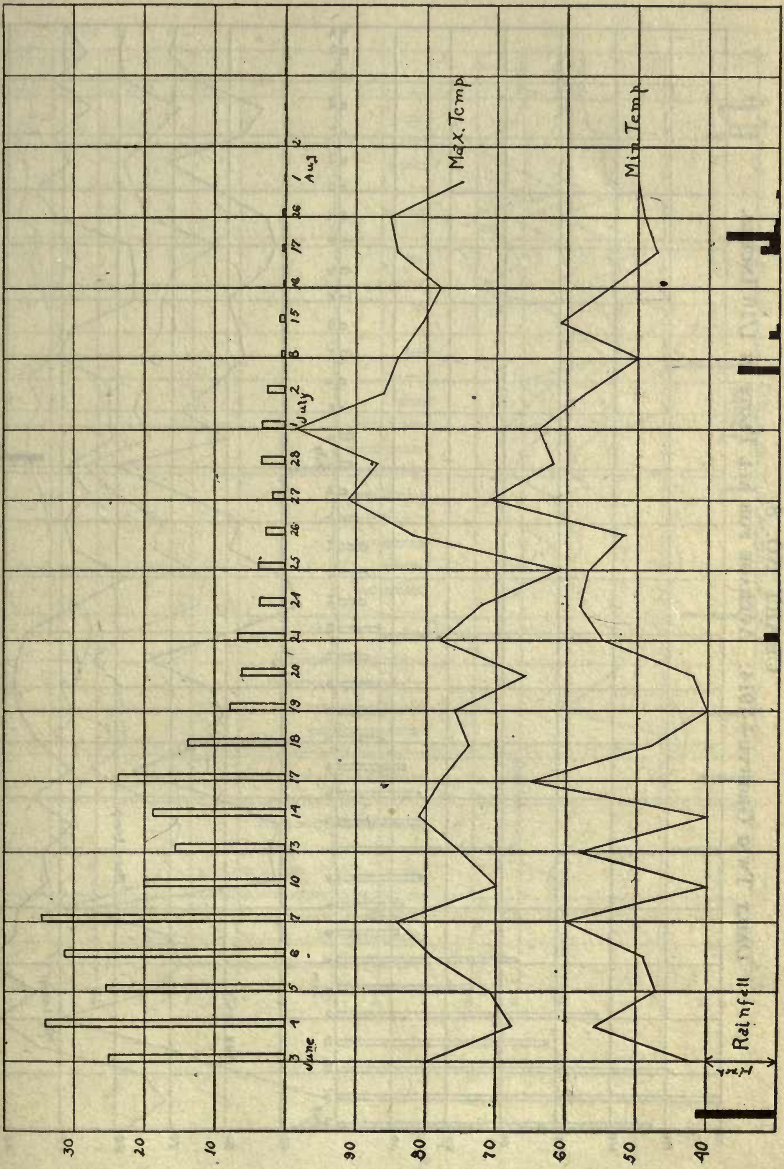


CHART NO. 8.

Daily Twig Growth—1914. Average for all Plots in 1/16 Inches.

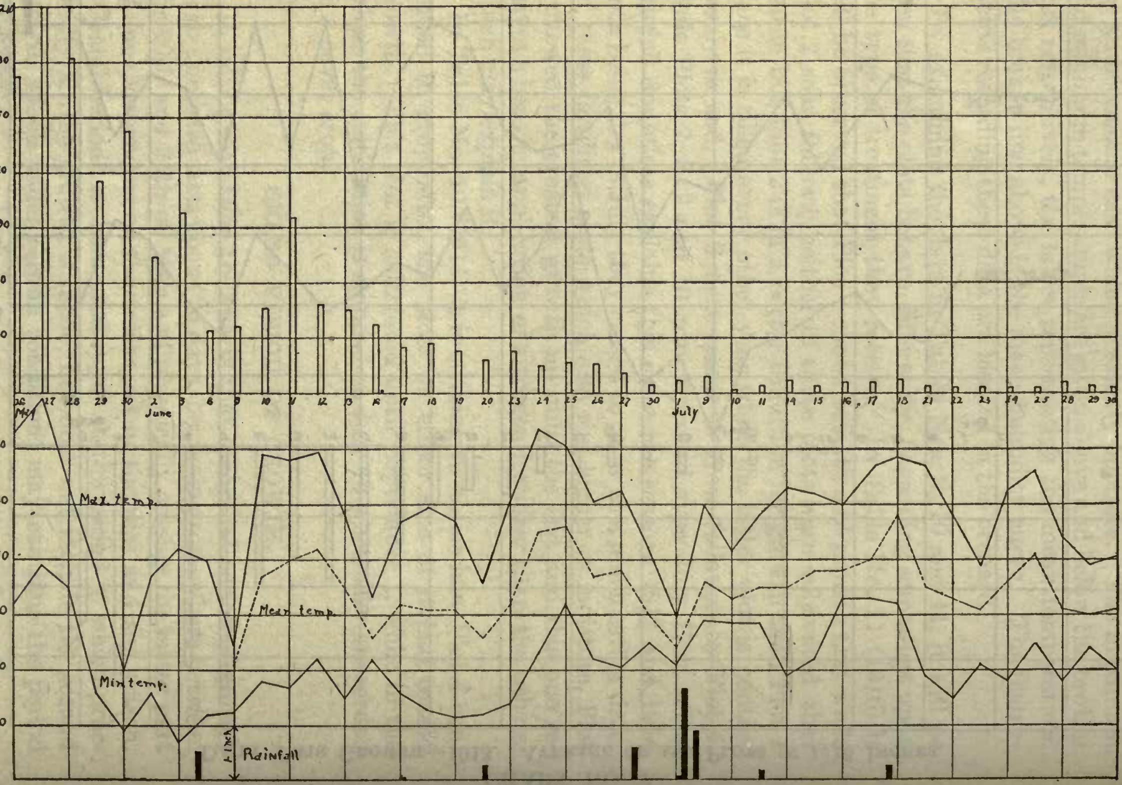
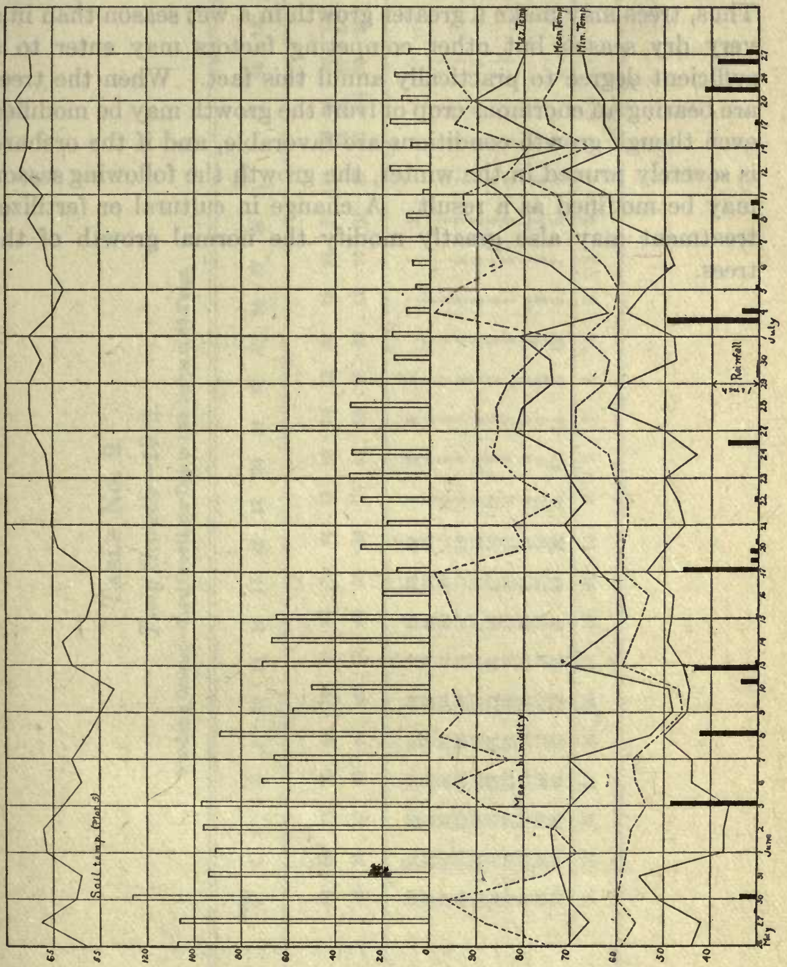


CHART NO. 9.

DAILY TWIG GROWTH—1916.



SUMMARY.

The relation of external factors to growth of a mature bearing apple orchard seems to be quite complex and not easily analyzed. Thus, trees may make a greater growth in a wet season than in a very dry season but other competing factors may enter to a sufficient degree to practically annul this fact. When the trees are bearing an enormous crop of fruit the growth may be modified even though growth conditions are favorable, and if the orchard is severely pruned in the winter, the growth the following season may be modified as a result. A change in cultural or fertilizer treatment may also greatly modify the normal growth of the trees.

TABLE No. 9.

Twig Growth—1913.

Woodman Orchard—Total Growth per Day in 16th Inches of 80 Twigs.

Date	June 3	4	5	6	7	10	13	14	17	18	19	20	21	24	25	26	27	28	July 1	2	8	15	16	17	26	Aug. 1
Air Temperature																										
Max.	80	68	71	79	84	70	75	81	78	74	76	66	78	72	61	82	91	87	101	86	84	80½	77½	84	85	75
Mean.																				74	65	67	64	68	67	64
Min.	42	56	47	49	60	40	58	40	65	48	40	42	55	58	57	52	71	62	67	57	46½	50	54	47½	42	49½
Plot 1	20	32	25	27	34	16	11	18	22	21	4	1	4	2	...	...	1	1	1	...	...	...	...	...	...	...
Plot 2	29	34	21	35	35	20	14	15	18	11	6	5	3	1	2	1	...	...	1	...	...	...	...	...	...	...
Plot 3	24	40	22	36	32	19	23	20	29	12	12	5	8	7	4	5	1	4	2	2	...	1	...	...	...	...
Plot 4	24	26	23	23	22	15	11	12	17	10	4	4	7	4	1	3	2	2	3	2	...	1	...	...	1	1
Plot 5	30	35	30	32	42	22	17	21	27	13	8	11	8	8	3	5	3	3	4	1	...	3	2	1	1	...
Plot 6	28	35	22	28	24	12	13	16	17	10	10	9	2	2	2	5	4	5	4	2	...	1	...	...	...	...
Plot 7	22	25	23	28	34	18	16	17	22	11	6	5	7	...	5	1	1	2	5	3	...	1	...	1	...	1
Plot 8	24	34	22	32	33	29	12	25	24	15	6	9	8	3	2	...	1	2	1	...	3	...	...	...	...	...
Plot 9	26	34	27	26	41	23	16	16	28	15	10	5	9	3	7	2	5	5	5	6	2	...	...	...	...	...
Plot 10	26	42	36	43	45	23	22	27	32	20	13	17	11	6	12	5	7	8	5	7	...	...	...	...	...	...
Av.	25	34	25	31	34	20	15	19	24	14	8	7	7	4	4	3	2	3	3	2	0.5	.7	.2	.2	.2	.2

TABLE NO. 10.

Woodman Orchard—Total Growth in 16th Inches per Day.

Basis, 400 Twigs—1914.

	May					June																			July	
Date	26	27	28	29	30	2	3	6	9	10	11	12	13	16	17	18	19	20	23	24	25	26	27	30	1	9
Air Temperature																										
Max.	93	99	83	68	50	67	72	70	55	89	88	89	78	64	77	79	77	66	81	94	91	80½	82½	72	59½	80
Mean.									51	67	70	72	65	56	62	61	61	56	62	75	76	67	68	60	54	66
Min.	62	69	65	46	39	46	37	42	43	48	47	52	45	52	46	43	42	42	44	53	62	52	50½	55	51	59
Plot 1	134	134	101	63	46	46	15	...	10	7	4	3	5	...	...	...	...	...	...	...	...	...	...	...	...	...
Plot 2	197	255	180	151	116	104	64	23	19	9	29	14	11	29	8	...	...	...	...	...	...	...	...	...	...	...
Plot 3	111	158	112	54	90	45	50	12	22	12	50	29	18	9	5	14	5	5	6	6	3	6	...	...	...	...
Plot 4	144	150	156	93	75	54	78	27	36	24	79	45	36	69	17	13	13	16	17	10	13	8	5	2	5	1
Plot 5	111	159	165	105	102	69	63	30	36	36	73	33	45	21	18	12	12	12	12	9	9	...	3	3	3	...
Plot 6	159	162	150	114	96	78	57	39	48	45	107	37	37	20	21	27	21	18	18	9	15	15	9	3	6	6
Plot 7	224	198	234	158	108	97	101	61	54	72	137	72	79	43	43	50	43	29	39	29	4	22	22	3	7	7
Plot 8	163	214	176	101	105	69	76	42	34	56	105	50	38	38	14	21	14	17	17	17	10	21	14	11	17	21
Plot 9	230	360	278	200	117	105	240	74	62	110	211	113	100	77	67	81	72	48	67	38	67	43	24	12	19	24
Plot 10	253	318	270	119	156	75	103	38	43	90	162	92	86	65	59	54	51	41	59	38	54	54	34	20	18	34
Av.	172	211	182	115	143	74	98	35	36	46	96	49	45	64	25	27	23	18	23	15	17	16	11	5	7	9

TABLE NO. 10—*Concluded.*

Date	July 10	11	14	15	16	17	18	21	22	23	24	25	28	29	30	Aug. 1	4	5	6	7	8	11	12	13	14	15
Air Temperature																										
Max.	71½	78	83	82	80	87	88½	87	78	69	82½	86	74	69	70½	84	63	69½	82	82	89	87	71	79	82	84
Mean.	63	65	65	68	68	70	78	65	63	61	66	71	61	60	61	67	59	61	64	66	74	77	68	66	70	69
Min.	58½	58½	49	52	63	63	62	49	45	51	48	55	48	54	50	54	51	51	48	53	61	70	58	54	53	52
Plot 1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Plot 2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Plot 3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Plot 4	...	2	0	3	3	0	4	3	0	0	3	5	11	5	3	10	3	5	7	15	6	15	15	8	5	10
Plot 5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Plot 6	3	...	6	...	6	3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Plot 7	4	7	14	7	7	7	14	11	7	7	3	4	14	6	6	9	11	9	4	11	6	9	6	...	4	...
Plot 8	7	8	14	11	14	17	17	14	8	8	14	6	14	8	8	11	8	6	6	4	8	7	6	4	7	7
Plot 9	8	10	16	12	12	19	16	8	14	10	8	10	14	12	10	16	8	10	8	10	10	8	6	...	...	...
Plot 10	1	14	22	14	22	18	27	14	9	11	9	9	9	12	7	6	6	5	3	3	5	3	1	...	...	...
Av.	2	4	7	4	6	6	7	4	3	3	3.6	3.3	6.2	4.3	3.3	5.1	3.6	3.4	2.7	4.2	3.4	4.1	3.4	1.2	1.5	1.7

TABLE NO. 11.

Twig Growth—1916.

Woodman Orchard—Total Growth in 16th inches per Day.

Date	May 26	27	28	29	30	31	June 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Air Temperature																									
Max.	71	66	56	78	71	72	74	74	69	71	77	65	71	53	48	49	59	67	71	65½	58	59	64½	71	72
Mean.	59	56	54	63	60	59	58	57	54	57	57	56	57	50½	46	47	53½	59	58	57	55	54	59	66	61½
Min.	44	42	52	52	50	46	37	37	36	46	41	46	44	48	45	44½	48	50½	46	48	48	48	54	51	51
Plot 1	92	82	...	131	97	53	52	57	53	...	83	49	32	40	30	8	...	43	24	11	23	13	6	...	53
Plot 2	123	96	...	170	148	77	81	80	91	...	105	68	28	81	26	23	...	64	36	27	44	15	7	...	58
Plot 3	126	102	...	227	138	87	132	112	121	...	174	92	91	103	38	38	...	101	56	41	73	27	18	...	114
Plot 4	160	112	...	254	136	107	91	138	100	...	174	82	69	94	35	60	...	101	54	40	55	32	15	...	115
Plot 5	106	115	...	235	128	108	72	107	87	...	149	49	51	93	41	28	...	96	43	46	46	17	12	...	81
Plot 6	99	107	...	241	116	92	95	95	101	...	152	60	91	73	46	21	...	99	53	56	34	17	14	...	94
Plot 7	78	136	...	178	139	92	99	107	124	...	167	67	85	113	33	31	...	127	68	41	38	27	16	...	92
Plot 8	80	104	...	270	97	95	89	91	84	...	134	53	62	70	49	30	...	97	41	47	34	14	24	...	104
Plot 9	81	118	...	...	122	91	89	82	93	...	...	100	66	94	39	35	...	...	51	81	45	17	12	...	...
Plot 10	126	90	...	258	142	143	103	97	120	...	222	91	89	132	50	32	...	135	84	81	64	28	18	...	211
Av.	107	106	...	196	126	94	90	97	97	...	136	72	66	89	39	31	...	86	51	47	46	21	14	...	94

TABLE No. 11—*Continued.*

Date	20	21	22	23	24	25	26	27	28	29	30	July 1	2	3	4	5	6	7	8	9	10	11	12	13	14
Air Temperature																									
Max.	67	71	67	70½	73	65	82	82	80½	74	75	81	83	79	63	68	74½	84	81	75	66	84	92	85	72
Mean.	59	58	58	61	62	61	67	69	69	63	62	67	69	67	61	60	63	68	71	67	61	73	82	78	66
Min.	48	43	47	49	43	57	34	49½	61	49	47	48	53½	61	58	52	48	50	62	56	56	62	72	70	49
Plot 1	2	...	8	7	7	...	11	50	17	1	9	3	...	2	...	...	...	...	...	...	11	...	2	...	4
Plot 2	26	8	11	14	13	...	25	56	23	13	5	13	...	15	4	2	...	2	...	...	14	2	5	...	2
Plot 3	50	24	27	30	39	...	74	98	39	53	6	16	...	45	24	22	2	14	...	...	54	4	26	...	2
Plot 4	41	44	32	38	57	...	70	59	56	25	22	27	...	40	12	...	8	12	16	...	22	8	19	...	2
Plot 5	24	17	28	27	38	...	61	65	28	43	15	16	...	49	8	16	...	34	12	...	22	2	18	...	10
Plot 6	38	13	33	23	30	...	60	56	24	36	8	8	...	28	12	...	12	28	16	...	10	4	22	...	12
Plot 7	23	19	35	22	27	...	44	69	24	28	13	4	...	46	2	6	4	30	8	...	12	...	24	...	14
Plot 8	17	11	22	21	27	...	36	60	39	16	11	12	...	29	2	2	16	22	7	...	10	2	20	...	12
Plot 9	17	20	38	32	32	...	...	57	39	31	24	24	...	...	12	4	12	32	12	...	...	...	...	...	...
Plot 10	35	29	64	65	63	...	129	88	64	64	40	36	...	74	26	10	14	40	30	...	36	10	42	...	22
Av.	27	18	30	28	33	...	51	66	35	31	15	16	...	33	10	6	7	21	10	...	19	3	18	..	8

TABLE NO. 11—*Concluded.*

Date	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Aug. 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Air Temperature																																		
Max.	76	83	83	84	93	91	72	83	73	82	78	76	80	76	77	74	93	81	80	78	83	75	86	87	92	69	68	73	85	71	78	81	86	86
Mean	62	71	75	73	80	76	68	75	71	73	72	72	72	66	65	68	77	70	65	69	73	70	73	73	79	63	63	64	71	63	64	66	69	70
Min.	47	55	63	63	67	63	67	66	69	66	70	70	66	61	49	61	66	51	46	60	62	64	61	61	69	60	60	61	61	61	50	49	50	55
Plot 1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Plot 2	..	..	12	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Plot 3	..	..	10	..	..	6	..	..	..	2	..	..	..	..	..	..	2	..	..	..	..	..	..	..	2	..	..	..	..	..	..	..	..	..
Plot 4	..	..	22	..	..	16	..	..	..	6	..	..	..	..	..	..	6	..	..	6	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Plot 5	..	..	26	..	..	22	..	..	..	20	..	..	8	..	..	..	22	..	..	10	..	..	..	..	14	..	..	8	..	..	10	..	..	4
Plot 6	..	..	10	..	..	8	..	..	..	6	..	..	2	..	..	..	8	..	..	4	..	..	..	..	6	..	..	16	..	..	6	..	..	2
Plot 7	..	..	34	..	..	30	..	..	..	58	..	..	32	..	..	..	56	..	..	38	..	..	..	..	50	..	..	44	..	..	18	..	..	28
Plot 8	..	..	28	..	..	22	..	..	..	26	..	..	16	..	..	..	32	..	..	26	..	..	..	..	28	..	..	20	..	..	20	..	..	14
Plot 9	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Plot 10	..	..	22	..	..	22	..	..	..	34	..	..	38	..	..	..	42	..	..	18	..	..	..	..	38	..	..	20	..	..	8	..	..	6
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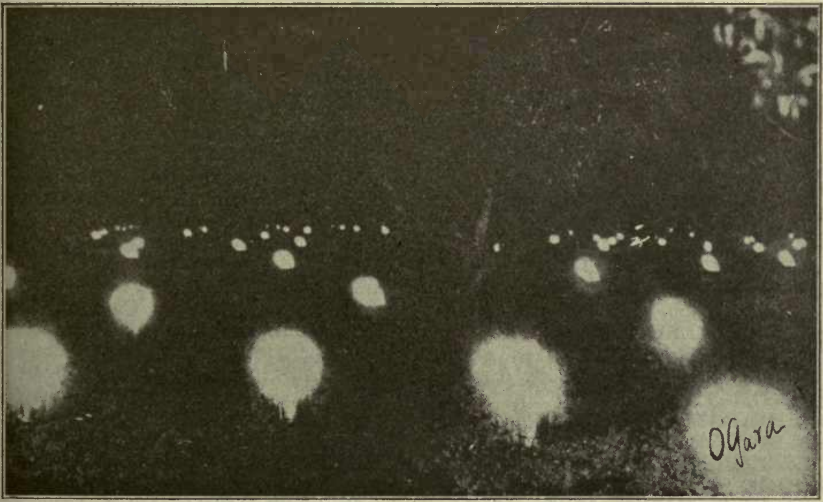
Bulletin No. 161



Orchard Heating

By

FRANK L. WEST and N. E. EDLEFSEN

Logan, Utah, October, 1917

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Orchard Heating

By

FRANK L. WEST and N. E. EDLEFSEN*

INTRODUCTION

In the state of Utah scarcely a year passes without some damage being done to farm crops, either in the spring or the fall, because of the occurrence of killing frosts. For example, in the spring of 1916 the tops of the young beets were frozen, about one-fourth of the grain of the northern part of the state was frozen, the yield of the first crop of alfalfa was about half normal and 90 per cent of the fruit of the state was destroyed. During the month when fruit buds are in bloom, the report of the U. S. Weather Bureau shows that on an average covering ten years for the five leading horticultural counties, freezing temperatures of 30 degrees, or below, are experienced six nights a year. The county agricultural agents report that three years out of ten the fruit crop is somewhat below normal due to frost, that the crop is considerably below normal one year out of ten for the counties, and that certain orchards in the counties frequently lose their entire crop.

The states of California, Oregon, Colorado, Washington, Ohio, and even as far south as Florida have been heating their orchards on quite a large scale, especially the first two states. Heating on a small scale is being done in parts of more than a dozen other states. (a).

It is the purpose of this bulletin to report the results of our experiments on orchard heating, to answer the question as to the conditions under which artificial heating would be financially profitable, and to give the most approved method of carrying out the work.

DELAY OF TIME OF FLOWERING

The later the buds bloom in the spring, the less chance of their being frozen, because as the spring advances, the temperature in the orchards increases and the chance of a killing frost occurring becomes less. It has been suggested that the development of buds be retarded either by piling snow about the base of the tree, or by whitewashing it. The snow would have but a very slight effect, if any, on the temperature of the tree branches and would not sensibly change the temperature of the roots and we, therefore, believe that treatment to be valueless. Although the whitened surface of the tree would reflect a high percentage of the energy that falls upon it, and would consequently absorb a smaller amount, yet unless the light-colored material that is applied is valuable as an insecticide, the method is of doubtful value.

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*The authors wish to acknowledge their indebtedness to Dr. L. D. Batchelor (now of the University of California), and W. H. Homer, for valuable suggestions; Mr. Frank Gates for assistance in making the electric heaters; and Mr. J. Z. Richardson and Mr. W. E. Goodspeed for help in making the observations.

(a) . Monthly Weather Review, October, 1914, No. 42, pp. 562-592.

Numerous devices for the prevention of frost injury have been tried. Among the methods used are: Hanging small kerosene lamps in the trees, drawing canvass around the trees on a cold night—for very valuable orchards, the drawing of canvass over a permanent framework built above the trees—and for small plants, covering them with straw or paper and plowing a furrow between the rows and thereby throwing the loose dirt over the foliage. In some cases orchards are heavily irrigated on the night of an expected frost and with reported success in not a few cases. Spraying the orchard with water has been recommended. If the cost of producing the fruit is less, if the fuel is cheap, and if there is an excellent market for the fruit so that it will bring a high price, then it may be profitable to heat with oil burners; but we do not think smudging without heating is satisfactory.

SOIL TREATMENT TO MODIFY MINIMUM AIR TEMPERATURE (CONDITION OF GROUND AND ITS COVERING)

The attempt has been made, and with some success, to treat the soil in such a way as to prevent the minimum temperature of the air above the ground from going as low as it otherwise would do. The rate of loss of heat from the ground to the air above during the night depends on the difference in temperature between the air and the ground. The larger this difference, the more rapid is the rate of heat transfer. The treatment consists in lowering the heat capacity of the ground so that the same amount of heat falling upon it in the day time will cause a larger rise in temperature and therefore a larger amount of heat will be given to the air by the ground during the hours when frost is liable to occur. This has been successfully done by Professor

Henry J. Cox (b) of the U. S. Weather Bureau working in the cranberry districts of Wisconsin. . Sections of these bogs were drained, sanded, cultivated, and either left bare or thinly vined. This resulted in a lowering of the heat capacity of the ground. The highest maximum soil temperatures for the day, the lowest minimum soil temperatures for the night, and the highest minimum air temperatures occurred in these sections, while in the uncultivated marsh, which was poorly drained and had a thick growth of vegetation on it, just the reverse was found to be true; the minimum temperature of the air in the sanded section being seven degrees higher than in the untreated bogs. The unfortunate thing about this method when applied to orchards is the fact that these differences in temperature of the air above the districts mentioned disappears at a height of three feet above the ground; that is, the method is ineffective in modifying the minimum temperature of the air at heights above three feet.

FROST AND CLEAR NIGHTS

The earth receives heat from the sun during the day, and during the night this heat is continuously lost by radiation to outer space, for which reason the temperature usually falls all night long, the rising of the sun starting the cycle again. It has been observed that on clear nights, the minimum temperature is low (frosts usually occur on clear, quiet nights) while on cloudy nights the air does not become so cold. The explanation lies in the fact that the clouds act as a mantle which holds the heat in and prevents it from being dissipated into space. It has been proposed that, on the occasion of a clear night when the weather threatens a frost, the orchard be covered with an artificial cloud or mantle. This mantle is for the purpose of keeping the heat in the orchard that was stored in the ground on the previous day when the sun was shining. It is also supposed to keep the temperature from rising too fast the next morning, when the sun comes up, the feeling being that if the buds have been frozen the damage would be less when the rate of thaw is slow.

SMUDGE

With these points in mind, various methods of smudging have been practiced; a common one being that of drawing through the orchard a wagon covered with wet burning straw, so that the smoke and the evaporated water would hold the heat of the ground in the orchard area. When heat starts through a gas, part of the heat is absorbed and part of it goes through unobstructed. The gases that are the best heat absorbers and therefore the ones that would prevent the escape of the heat of the ground best are water vapor, carbon dioxide, ammonia, gaseous hydrocarbons, dust, and smoke. These would be the best mantles. (c-d).

(b). Descriptive Meteorology, Moore pp. 108-109.

CARBON DIOXIDE AS A SMUDGE WITHOUT THE ADDITION OF HEAT

During the spring of 1910, under the direction of Prof. W. H. Homer, Jr., who was then Horticulturist at the Utah Experiment Station, ninety-six pounds of carbon dioxide were liberated in one acre of an orchard during a period of two and one-half hours in the night by drawing a tank of the gas, with the valve opened, back and forth through the area mentioned. This gas not only failed to keep the treated area warmer than the adjoining section, but actually cooled it slightly. This may be due to the fact that the gas as it leaves the tank expands rapidly because of the fall in pressure and therefore cools to a temperature of about 32° F. Difficulty was experienced in liberating the gas because the valve kept freezing up. (This subject will be considered further, at a later point in the bulletin.)

SPRAYING OF WATER

Inasmuch as water is a good heat absorber, it was thought that to spray water into the air above the trees might be effective in preventing injury by frost. In the spring and fall of 1912, we so treated an acre of apricots in the orchard of W. H. Homer, Jr., at Pleasant Grove, Utah, at his suggestion. It indicated probable success from the fact that the source of water supply had a temperature of 55° F. and, having at hand a large amount of it, it was expected that considerable heat would be given out to the orchard when this water cooled to 32° F., the heat capacity of the water being so large, and that again on arriving at 32° much heat would be again evolved as the water froze. When the sun fell on the orchard in the morning, we had hopes that the air would not warm up so fast as the air in the adjoining orchard, and that because of the slow rate of thaw the damage would probably be less. This water was piped to the top of each of the trees and was forced out under 50 pounds pressure in a

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(c). Preston—Theory of Heat, p. 556.

(d). Weather Bureau Bulletin C, D, and G, p. 125.

fine spray to a distance just sufficient to cover very thoroughly the entire tree. Eight standardized thermometers were placed at various points in the treated section, always at the same height above the ground. The same number were placed around the outside of this section. A small, wooden shelter four inches wide and a foot long was placed over each thermometer in order to keep it dry, since it was hung in the branches of the tree from which water was dripping as in the heaviest of rain storms. Without any water being applied, the mean reading of the thermometers inside the area in question was the same as the mean reading of the check thermometers to within a fraction of a degree. With the spray on two nights, the treated section was found to be 0.5° F. colder than the air outside and was the same both nights. The spray was left on until noon, and although the air was warming up, yet the mean temperature underneath the cloud was one morning 1.1° F. colder than the adjoining section and the other morning 2.5° F. colder, showing that the cloud hung over the orchard did slightly retard the rate of warming up when the sun arose in the morning; the effect was very slight, however. A test showed that the air was practically saturated in the trees when the spray was on.

On the night of April 14, 1912, a frost was experienced and the spray was turned on. The apricots were in full bloom. Ice as thick as one-fourth of an inch formed on the twigs and branches and this weight was so great that the branches began to break. A count of the damaged buds was made the next night, and it was found that those on which the ice formed were killed and that no fruit was obtained from this acre in the fall. The apricots in the other part of the orchard were not damaged by the frost at all, and a normal yield was obtained. The spray, therefore, instead of protecting the orchard from frost, actually damaged it. We had earlier observed in determining the injury that had been caused to the fruit buds in the College orchard at Logan after a night of freezing temperature associated with a storm of sleet, that those buds that were open and were turned up were frozen, while the majority of the buds that were turned down and did not collect snow and sleet in them were not injured. The same thing has been observed elsewhere since then. Finer openings might have been made in the nozzle and the application made higher above the trees, thus tending to merely increase the humidity of the air by evaporation. These smaller openings would become clogged because our equipment gave trouble for this reason, and it is awkward to get to the very top of the trees to clean them, and if the amount of water applied be reduced sufficiently to prevent condensation on the trees, it is very doubtful whether enough has been applied to form effectively a smudge, as the experiments to be reported later on in this bulletin, using carbon dioxide as a smudge, tend to show.

AMOUNT OF HEAT IN THE SOIL THAT THE SMUDGE IS TO RETAIN

The essential idea in smudging is to maintain an atmospheric blanket over the orchard that will keep in the heat that was stored in the ground during the previous day when the sun was shining. Is there much available heat stored in the ground during the day? Except for four hours in the middle of the day, the temperature of the ground is colder than the air during December, January, and February. In June, July, and August, except for five hours around noon, the ground is only 2 degrees warmer than the air. (e). The ground, then, during the night is never much warmer than the air. Again, suppose that the difference in temperature between the maximum of the afternoon and the minimum of the air for the early morning be 30 degrees for the day, then at a depth of four inches in the soil the daily range of temperature instead of being 30 degrees will be one-half of thirty, or fifteen degrees, and, at a depth of eight inches, the range of temperature is one-fourth, or 7 degrees. The daily change in temperature is not felt at depths in the soil below three feet. It is thus seen that this small excess in temperature of the soil over the air is only found in a comparatively thin layer of the soil at the top. Furthermore, in Utah these freezes in the spring nearly always follow a storm when the ground is wet, the sky has been overcast with clouds and very little heat has collected in the ground during the day. (f). "In general the ground will be warmer even in winter than that which is precipitated upon it," hence the rain has cooled the ground and what little sunshine there has been during the day has been used in evaporating the water instead of warming up the ground during the day. Whether the frost follow a storm or not, it is nearly always true that when we have one night with frost, we usually have three to six in succession and that the days between these frosty nights are not nearly so warm as usual;

(e). Descriptive Meteorology—Moore, p. 87.

(f). Descriptive Meteorology—Moore, p. 88.

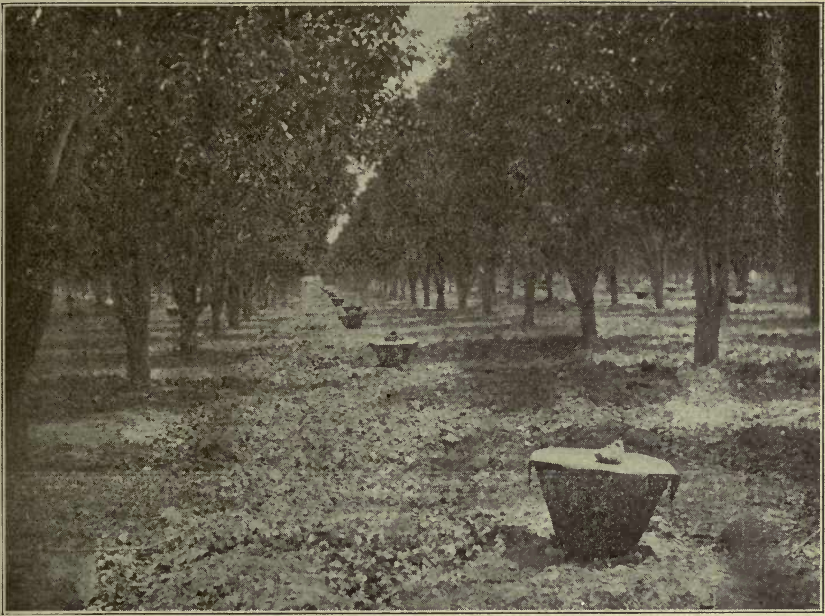

Figure 1.—One type of orchard heater.

hence if the smudge were to keep the heat in the air just above the ground the first night there will be little radiated to the air about the trees the second or third night, because the ground would be but very slightly if any warmer than the air.

COLORLESS OR SMOKING FIRES

In the early days of heating, the question arose as to whether a plentiful supply of air should be supplied and a colorless heat produced, or should only a limited amount be supplied and have the burning associated with smoke. In the first case more heat would be produced from the same amount of fuel, but in the last case smoke is produced. The unburned material, in the case of coal, would be small particles of carbon, and, in the case of oil, gaseous hydrocarbons and carbon both of which are very good absorbers of heat, but it should be remembered that in the complete combustion of either of these fuels, carbon dioxide and water vapor are developed, which substances though colorless are also very good heat absorbers. (g)

(g). Where whole communities have done considerable heating, damage by the smoke to the house furnishings has been complained of

According to Prof. W. J. Humphreys, (h) of the U. S. Weather Bureau, soot of the proper degree of fineness is several thousand times more effective than carbon dioxide in intercepting earth radiation. With smudge pots and coal baskets, only a small percent of soot is produced, most of the fuel being burned to carbon dioxide.

ELECTRIC HEATERS

To test the relative merits of the heat and smudge we decided to do some heating by means of electricity, where no smudge is liberated and note the effect and then add to the air about the electric heaters carbon dioxide, and thereby see if the smudge caused the air about the heaters to be warmer than it was before it was added. The results of the heating done by other investigators have been given in terms of the number of heaters to the acre and the resulting rise in temperature. The rise in temperature of course would depend on the rapidity with which oil is burned and on the calorific value of the fuel. By heating electrically we can readily control the amount of heat supplied, and can determine just how much is being delivered by reading the electrical measuring instruments. It was distinctly understood from the beginning that the cost of electrical power is such that it would be impractical for the farmers to heat their orchards in times of frost by means of electricity.

We made some electric heaters of about ten kilowatt (12½ horse power) capacity, this being about the capacity of the gallon size oil smudge pots, by making coils out of No. 14 galvanized iron wire and fastening these coils on porcelain insulators that had been bolted to small iron frames. These heaters cost $1.35 a piece.

EXPERIMENT ON HEATING, WITH AND WITHOUT SMUDGE INSIDE A LARGE BOX

We took two large wooden boxes that had been used for shipping expensive art pictures and which had therefore been specially lined, being almost air tight, knocked the bottom out of one and placed it on top of the other, giving us an inclosure 2½ by 4½ and 7⅓ feet deep, which was nearly air tight. This box was taken out in the open air in the court of the Mechanic Arts building of the College and four electric heaters were placed in the bottom of it, the heaters being connected in series so that the power consumption was but ⅔ horse power. Nine accurate thermometers were placed inside the holes in the box on different sides and at different elevation and one was hung down in the center. Check thermometers were placed around outside the box. As a mean of four experiments which had been run from one-half hour to two hours after a steady state had been reached the thermometers being read every five minutes, the box maintained a temperature of 14.1° F. higher than the mean air temperature outside the box. A hose was attached to a tank of carbon dioxide and this hose introduced into the bottom of the box through a hole in the side. This cold gas was allowed to enter the box as fast as it would run out of the tank. The excess of temperature of the air inside the box over that outside was now found to be 14.3° F. being but 0.2° F. warmer with the gas than without it. Of course the gas that entered was cold, due to its expansion on being liberated from the tank. We next warmed the gas by surrounding the hose with warm water so that the gas entered the box at approximately the temperature of the air in this box. The mean raise in temperature now was found to be 16.9° F. This is now 2.8° F. warmer than without the gas. Twenty-two pounds of carbon dioxide were liberated in the box in fifty minutes, making a volume sufficient to fill it three times. At various times during the experiment samples of air were extracted from the interior of the box and the analysis of these showed an average of 3 per cent of the air as carbon dioxide. Without the use of the carbon dioxide it required 6½ watts per square foot to raise the temperature 1° F.

(h). Bul. Mt. Weather Obsy., 6, 1913.

HEATING OF A SHELTERED AREA

If heating be done in the court of a one story building, the air space being open to the sky but surrounded by brick walls we should get approximately the same result as that obtained when many acres are simultaneously heated in the orchard because in this latter case heat is being passed both ways horizontally from different heaters and in the inclosure the heat that strikes the walls will in part be returned to the air space, e. g., if one heater were placed in a room without a roof, the walls would prevent the escape of the heat that struck them and would reflect it back into the middle of it and yet the effect would be the same if the wall were removed and another heater was placed on the other side of it for now the heat that the wall would have reflected back is supplied by the other heater.

CARBON DIOXIDE AS A SMUDGE WITH THE ADDITION OF HEAT

Near the center of the Mechanic Arts building of the College there is a space of 500 square feet that is surrounded on all sides by one story brick walls and yet is open at the top. Thermometers were distributed in this space and a like number were placed in the open country away from the building. The thermometers were read at regular intervals after the sun went down as the air in both places cooled. They both cooled at the same rate, the mean temperature inside remaining almost exactly the same as the mean of the outside thermometer readings. By means of a hose, carbon dioxide gas was liberated throughout this space as fast as we could get it to run out of the tank, the neck of the tank being surrounded by cloths kept soaked with hot water to prevent the opening to the tank from freezing up· The mean temperature inside remained the same as that outside, both cooling of course as the night progressed but both cooling at the same rate. The carbon dioxide appeared to be valueless as a blanket for holding the heat inside the inclosure.

AMOUNT OF HEAT REQUIRED TO WARM AIR

Six heaters were distributed in this inclosure and were connected so that the electrical power transformed into heat was 40 K. W. Five thermometers were distributed in the space and hung up about five feet above the ground. A like number were placed away from the building at the same elevation above the ground. As a result of six experiments, each one running for two to three hours, and the thermometers being read every ten minutes, the mean temperature of the outside section being 52° F. it was found that the air inside was maintained six degrees Fahrenheit warmer than the air outside. An anemometer was used to give the wind velocity, and in spite of the fact that the heated area was sheltered or protected on all sides, the wind was unusually effective in cutting down the rise in temperature inside the heated area. The wind velocity varied from a calm to ten miles an hour and in the case of the latter wind, the rise in temperature was but 2·9° F. while with no wind the temperature inside exceeded that of the check thermometers outside by 9.6 degrees, the mean of all the experiments being as stated above six degrees. The wind velocity was measured on top of the building. Assuming the rise in temperature to be proportional to the amount of heat supplied—which assumption would be very close to the truth for the rise in temperature is small—the results show that it required 14 watts per square foot to raise the temperature 1° Fahrenheit.

With the same amount of power applied again, viz. 40 K. W. (50 horse power) to this inclosure, with the wind blowing ten miles per hour, 18.5 lbs. of carbon dioxide (i) were liberated in about half an hour and the mean temperature inside was but 2.8° F. above that outside and then again on another occasion, 30 lbs. of carbon dioxide were liberated in 50 minutes with the same amount of power developed and with no wind and the mean difference in temperature was 8.8° F. This was just as much gas as we could get out the tank for in spite of the hot water applied to the neck of the cylinder, it kept freezing up. It appears that the carbon dioxide had little effect in keeping the temperature about the heaters above that outside.

All of the heaters were now placed in the open away from buildings, being distributed about as smudge pots are distributed in the orchard, and from 75 to 90 K. W. (more than 100 H. P.) of power applied. Eight thermometers were used; these were read every ten minutes after a steady state had been reached and the mean taken. As a result of six experiments—the mean temperature of the air outside of the heated area being 70° F.—the heaters caused a rise in temperature of 11° Centigrade or 20° Fahrenheit and the anemometer showed a wind velocity varying from a calm to five miles an hour. As an average it required 13 watts applied to a square foot to raise the temperature 1 degree Fahrenheit.

AMOUNT OF HEAT REQUIRED FROM SMUDGE POTS AND ELECTRIC HEATERS COMPARED

Considering the common smudge oils as giving out 18,800 British Thermal units of heat per pound that is burned and considering a gallon of this oil to last four hours and remembering that with 100 heaters to an acre we get a rise in temperature of approximately 4 degrees Fahrenheit, it figures out that these smudge pots develop 6 watts per square foot in raising the temperature of the air in the orchard 1° Fahrenheit. This value is only very approximate. (See page 17 this bulletin). With the electric heaters in the box mentioned earlier it required 6½ watts per square foot per degree and in heating in the open with about 100 H. P. it required 14 watts per degree per square foot. This larger value for the electric heaters than for the smudge pots is probably due to four causes. The electric heaters give out no smudge (colorless flames in the case of any organic combustion give out carbon dioxide and water vapor, an effective smudge). In the experiments with the electric heaters the rise in temperature was from 20° F. to 40° F. above that of the surrounding air while in the case of the smudge pots the rise was only about 4° F. The greater the difference in temperature the greater the rate of loss of heat and thus the more power would have to be supplied to get it 1° warmer. The electric heaters were not placed in the orchard because the electric power was not available there. The foliage on the trees in the orchard would make it easier for the pots to warm it up. The tests with the smudge pots were made in the orchard at night when as a result of slow cooling the temperature gradient in the air was negative, while the experiments with the electric heaters were performed either in the late afternoon or in the evening just before midnight when this was not true. It is largely because of this temperature inversion in the early morning, that it is possible to satisfactorily or sufficiently heat the orchard.

(i). Plenty of gas was liberated because when 1000.0 lbs of coal in 20 lb. pots distributed over an acre burned 3.5 hours gave a rise in temperature of 5.6 degrees Fahrenheit, (Farmers Bull. 104, p. 20). This when burned, produced 2660 lbs. of carbon dioxide, or .06 lbs. per square foot. At the end of the first half hour there would be approximately .008 lbs. per square foot. And if the gas rises to a height of fifty feet the lower air would have on an average of .2 per cent carbon dioxide at the end of the first hour. In our experiment where 18.5 lbs. of carbon dioxide were liberated in the inclosure, the gas was not warm and being heavier than air it would stay largely within the inclosure. This being true there would be .037 lbs per square foot and an average of 3 per cent carbon dioxide which is about 15 times as much as resulted from the burning of the coal.

TEMPERATURE INVERSION AND EXPLANATION OF EFFECTIVE HEATING

Normally the higher in the air one goes the colder the air becomes, the temperature falling 1° Fahrenheit for about 350 feet rise. At a height of about six miles, the temperature is about 50° Fahrenheit below zero. At night after the sun goes down, the air and the ground begin to cool but the ground cools much faster than the air, so that by early morning it is found that the soil temperature is lower than the air and hence as you rise from the ground, the air gets warmer to a maximum at a height of about 300 feet depending on the night, and then as you go still higher it begins to get colder. This warm air at this height should not rise even though it is lighter than that above it unless the temperature gradient just above the point of maximum temperature is larger than the adiabatic rate, which is approximately 1 degree Fahrenheit to every 183 feet rise, assuming no condensation to take place because of low humidity.

When this condition exists and the smudge pots are lighted, the hot air from them instead of rising to the very top of the atmosphere because of its lightness is heated slightly and being lighter than the cold air near the cold ground begins to rise and yet cooling as it rises becomes colder and hence heavier than the air at the above mentioned height of 300 feet hence does not rise to this point but stops. Suppose the air near the ground to be at a temperature of 28° and that at a height of 300 feet it is 38°. Then if the air about the smudge pots is warmer 2° or 3° to 31° or 32° it will rise to a height of about 50 or 60 feet at which height will be found air of the same temperature and density as that which is rising, so that if a moderate heat is supplied, not even the air up to the 300 level will need to be warmed. Instead of having to warm up all of the atmosphere above the heaters, we need simply to warm up a small part of the air below this level· This also explains how it is possible to warm up "all outdoors" with the small fires, why it is better to use many small fires instead of very hot large ones which would upset and remove this sort of ceiling and also why it is so very difficult to heat when there is even a slight breeze.

Considering the heating of the orchard through convection, the heat would rise to the artificial ceiling and stop and then this warmed region would gradually extend downward and after all the air from the tops of the trees to this ceiling had been warmed, then the trees would begin to warm up.

It is also interesting to observe that at the end of four hours, assuming no wind and diffusion as very slight, there would be over the orchard twenty four times as much smudge as there is at the end of ten minutes and yet it is the experience of investigators that it takes only a few minutes for an equilibrium condition to be established with a constant difference in temperature between the heated and unheated area.

Table I. Results Obtained by Various Investigators on Orchard Heating.

Page	Investigator	Kind of Fuel	No. of Pots per Acre	Kind of Pots	Rise in Temperature
20	(1) Whipple	coal	50	concentrated draft	6.0 deg. F.
20	"	"	80	open basket	4.4 deg. F.
20	"	"	100	Bolton	5.7 deg. F.
4	Lewis and Brown (2)	oil	45		1.0 deg. F.
5	"	"	75		3.0 deg. F.
29	"	"	39	Troutman	1 deg. F.
33	"	"	50	Bolton	3.7 deg. F.
36	"	"	100	Troutman	4.1 deg. F.
37	"	"	100	Troutman	3.6 deg. F.
44	"	"	40	Bolton	2.0 deg. F.
78	Woodbury and Wellington (3)	"	42	Bolton	1.7 deg. F.
78	"	"	85	Bolton	3.1 deg. F.
78	"	"	85	Haswell	3.4 deg. F.
86	"	"	100	Troutman	4.4 deg. F.
	Limoneria Orchard Co.		100*		6.0 deg. F.

1—Farmers' Bulletin 104.
2—Oregon Station Bulletin 110.
3—Indiana Station Bulletin 154.

*They report one pot to a tree and a rise in temperature of 6 deg. F. Using 100 oil pots and 50 coal baskets to an acre, they saved their lemon crop against temperatures lower than 20 deg. F.

From the above results it is seen that one can expect to keep the orchard, when near the freezing point, at least 4° F. warmer than the outside temperature when 100 heaters are used to the acre; and no less than that number should be used if one expects success. If cold winds of velocity more than ten miles an hour are bringing to the orchard large quantities of cold air besides disturbing the temperature inversion condition, unless whole communities are heating simultaneously it is not feasible to heat the orchard because a warming of even 1° to 1½° is obtained with difficulty under such conditions.

HEATING IN CALIFORNIA

Thousands of acres of oranges and lemons are successfully heated by oil pots in California and with reported financial success even though they have had to heat as many as thirty times a season. These crops have been saved against freezing temperature as low as 20° F. (j). Although they recommend but 100 heaters to the acre, yet against the above mentioned extreme frost they used considerably more to the acre. Oil in California costs only about one-half what it costs in Utah, the investment and crop are worth much more than in the Utah orchard, and the freeze that they experience is the one that occurs on a still night with a clear sky and with the whole community heating simultaneously. The usual freeze in Utah is associated with north winds after a rain, the sky clearing as the wind wanes, after which the temperature falls quite rapidly. They report average rises in temperature of more than 6° F. as a result of heating. Telephones are installed and the oil is piped throughout the orchard and the whole method including their cooperative work on forecasting with the weather bureau has been worked out to a nicety. They do not heat, as in other states, to protect the buds but rather to protect the matured fruit and occasionally the whole tree from freezing.

(j). Monthly Bulletin, State Commission of Horticulture, Sacramento, California, January, 1914.

COAL OR OIL AS FUEL

From a study of the work of other investigators on the subject of orchard heating, it is difficult to determine the relative amounts of coal and oil burned per hour that will give the same rise in temperature because there is considerable variation in their results. For the purpose of making a comparison of the cost of heating with the two kinds of fuel we will use the following statement from the Weather Bureau: "It is considered that one ton of coal will equal 100 gallons of oil in heating value." (k). Fifty heaters burning 40 pounds of coal would have to produce the same rise in temperature as 100 heaters burning a gallon of oil each in the same time interval, which is no doubt only approximately true. The coal then weighs 2½ times as much to produce the same result. A pound of oil gives out very approximately 1½ times as much heat so that if the above quoted statement is correct, 1⅔ times as much heat has to be developed by the coal, in order to produce the same rise in temperature as with the oil. More accurate data are needed to make this comparison what it should be, but in the following calculation we will use the above quoted figures.

(k). Weather Bureau No. 542, Feb. 11, 1915, p. 577.

COMPARISON OF THE COST OF HEATING TEN ACRES, TWELVE NIGHTS IN TEN YEARS WITH OIL AND WITH COAL, CONSIDERING A TON OF COAL EQUAL TO 100 GALLONS OF OIL.

WITH OIL

		For Ten Acres
1,500 Lard pail heaters at $0.20 (good for 10 years)		$ 30.00
12,000 Gallons oil @ $0.09		108.00
1 Wagon tank $50.00 (good for 15 years)		4.00
Lighting torches $10 (good for 10 years)		1.00
Thermometers $15 (good for 10 years)		1.50
Labor for handling the oil, pots and fires (for one year)		45.00
Storage tank 12,000 to 14,000 gallon $240 (good for 20 years)		12.00
Total cost for ten years		$191.50
Cost for one acre	$19.15	
Interest at ten per cent	1.91	
Total cost for one acre	$21.06	

WITH COAL

120 tons of coal @ $7.00 delivered		$ 84.00
500 baskets @ $0.25 (good for ten years)		12.50
Waste and crude oil for starting		10.00
Lighting torches $10.00 (good for ten years)		1.00
Labor for filling and lighting		45.00
Total cost for ten acres		$152.50
Cost for one acre	$15.25	
Interest	1.52	
Total cost for one acre	$16.77	

From the above figures it will be seen that with coal at $7.00 a ton and oil at 9 cents a gallon that coal is somewhat less expensive. It is probable that oil at 7 cents a gallon can compete with coal at $7.00 a ton.

The smoke from the oil fires and the high humidity associated with the low temperature by deposit darkens the trees and fruit somewhat, especially where heating is resorted to many nights during a season.

In the case of coal this trouble is not experienced and yet the smudge from the coal as far as retaining the heat is concerned is about as good as that from the oil. The coal heaters are a little harder to get started, their heat is not so easily regulated as with the others. With the oil heaters, the rate of burning can be controlled by adjusting the supply of air and in addition to the great ease of starting them, they can be put out by putting on the cover. The oil is somewhat easier to handle than the coal and all points considered, the oil is probably the better fuel to use.

EQUIPMENT NECESSARY FOR HEATING

For a small orchard the oil can be purchased in barrels and distributed to the pots in the orchard by hauling these barrels on an ordinary wagon or on a sled. The oil is much cheaper if it is purchased in carload lots; hence if the orchard is large or if several farmers can combine and buy a carload of oil, after getting bids on it then they should put up a storage tank made out of metal or concrete and purchase a special wagon for hauling this oil to the tank and later out into the orchard. The tank should be located if possible, on the hillside so that it may be filled from the wagon by gravity and also because the wagon can be filled from it by driving underneath. If this can not be done, a pump will need to be purchased. Torches should be procured for use in rapidly igniting the crude oil and several high grade thermometers should be distributed throughout the orchard. The heaters should be placed in the orchard in the early spring and after being filled with oil should be covered with the lid to keep the rain out. Arrangements should be made in advance for extra labor at the time of the frost because as a rule the heating has to be done several nights in succession and during the day time the pots have to be refilled.

FORECASTING FROST

In order successfully and profitably to protect an orchard from frost one must know when one should heat, because obviously fuel should not be burned when the frost is not severe enough to cause damage and when danger is near the fires should be lighted to prevent the injury.

The Section Director of the U. S. Weather Bureau at Salt Lake City would gladly loan to one orchardist in a locality, called the key station, a standard maximum thermometer, a standard minimum thermometer (in some cases a thermograph) and a shelter for these instruments. The orchardist is expected to read the instruments each morning during the blooming period of the fruit buds and telegraph these readings at his expense to Salt Lake City. About two hours later the Weather Bureau will telegraph back, at the government's expense, the forecast for the coming night and if the signs indicate a decided frost, he will probably telegraph that evening to the orchardist giving him a more accurate forecast based on later data. (1).

A farmer should have several minimum thermometers on his farm and determine the places where it is naturally coldest, i. e., where the frost hits hardest; he should also compare the readings taken in his own orchard with those taken on corresponding nights in the key station in order to be able to determine approximately how many degrees colder or warmer his orchard is than the key station, so that when the key station receives the forecast for that station he will know what to expect in his own orchard.

The difference between the maximum and the minimum temperature readings for the twenty-four hours is called the daily variation. The farmer should study his readings and determine the average daily variation for each week while the buds are in bloom. If then the average daily variation for the week be subtracted from the maximum temperature experienced in the afternoon it will give approximately the minimum temperature that will be experienced for the night. Clouds or winds usually decrease the daily variation. The minimum temperature for the twenty-four hours is a function of the dew point and the relative humidity determined the evening before, provided the weather map indicates a frost for that night, the constants for the imperical formula being determined for each locality.

The following frost indications given by Humphreys are helpful:

"1. An evening orchard temperature of about 40° F.

2. Clear skies, to permit rapid radiation from the surface covering.

3. No wind, or very light, to avoid mixing the warm atmosphere above with the cold surface air.

4. Wind movement, so far as there is any, from northwesterly direction.

5. Dew point below 32° F. to avoid the formation of a fog

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(1). This is accomplished through a study of the weather map. Explanations of how this is done are found in Milham's Meteorology, pp. 213-216.

blanket or the liberation of heat of condensation at temperatures above the freezing point.

But all these "signs" are only so many admonitions to be on one's guard in a matter where the price of success is eternal vigilance; they may be ever so helpful, but they are not infallible. (m).

Automatic frost alarms that can be purchased for about $45 may be set for a definite temperature and when this thermometer in the orchard cools to this temperature a bell will ring in the house.

WHEN TO LIGHT THE FIRES

It has been observed that after the temperature of the orchard has fallen below the danger point it is very difficult to raise its temperature, but if a moderate amount of heat is supplied at a temperature of about 30° F. and this amount be gradually increased as the temperature outside the heated area falls, the temperature in the orchard is thereby kept constant and above the danger point and thus the chances of the crop being saved are greater. At first only every second or third row of pots is lighted and then the thermometers are read. The others are lighted as they are needed. If heating is done at all it should be done with care and intelligence. The facts are that the buds are much hardier than most people think and many people have heated their orchards when the crop would have been saved without heating.

"A reading of the popular literature on the subject is likely to cause one to infer that the buds have a certain freezing temperature and that when they arrive at this temperature, they all freeze. This, of course, is wide of the truth. There is a range of four or five degrees between the highest temperature at which two or three per cent of the buds are injured, and the temperature at which all the buds are killed. It should be remembered that on the same branch are often found buds that have swollen but slightly when others are in full bloom. A freeze or two in the early spring will usually do no harm; they simply serve to thin the buds out, for it is generally known that there are many times more buds on the trees than actually mature into fruit. The number that one can allow to freeze and yet not heat the orchard will naturally depend on how many there happens to be on the tree at this particular time. It is very rare that a tree has so few buds that it cannot lose one half of them and yet mature an average crop in the fall." (n).

(m). Papers on Frosts and Frost Protection in the United States, Monthly Weather Review, p. 565. Oct. 1914.

Table II. Temperatures which buds in Cache Valley Experienced in the Spring of 1916 and the per cent Killed before the Fatal Freeze Came.

Kind of Fruit	Development	Temperatures Experienced	Development	Per Cent Killed	Temperatures Which Killed All
Jonathan Apples..	Showing Red	28, 25, 27, 24, 28, 28, 28.5	Full Bloom	32	16 deg.F.
Elberta Peaches	Almost Bursting	27.5, 27.5, 30.5, 31.5, 30	Fruit Setting	56	22 deg.F.
Pears.........	Showing Red	27.5, 27.5, 30.5, 31.5, 30	Fruit Setting	4	22 deg.F.
Jonathan Apples..	Well Swollen	27.5, 27.5, 30.5, 31.5, 30	Blossoms Just Gone	8	22 deg.F.

Table III. Yield of Different Varieties of Cherries in 1914 after they had been Subjected to a Temperature of 26 deg. F.

Variety	Development	Estimated Injury in Spring	Yield
Black Tartarian............	Petals Falling	None	66.6 lbs. per tree
Osthein........................	Full Bloom	None	125.0 lbs. per tree
Kings Monello..............	Full Bloom	9.5 per cent	130.0 lbs. per tree
Double Nattie...............	Full Bloom	48.5 per cent	100.0 lbs. per tree
Double Nattie...............	Buds Opening	20. per cent	125.0 lbs. per tree

It will be noticed from the figures in Table II that all the fruits mentioned except peaches can stand two or three freezes as low as 25° F., and still enough buds will remain uninjured to produce a normal crop. It must be kept in mind that all buds do not freeze at the same temperature. Part of this difference is due to difference in hardiness of the buds. They are also in different stages of development.

"The temperatures which will kill about 50 per cent of the buds of the Elberta peach are as follows: when they are slightly swollen, 14° F.; when well swollen, 18° F.; when they are showing pink, 24° F.; when in full bloom, 25° F.; and when the fruit is setting, 28° F. (o)." For data on other fruits see Utah Station Bulletin No. 151.

(n). Utah Bulletin No. 151—West and Edlefsen, 1917, p. 19.

(o). Utah Station Bulletin 151, 1917—West and Edlefsen, p. 22.

OCCURENCE OF FREEZING TEMPERATURES IN UTAH ORCHARDS DURING THE BLOOMING PERIODS FOR THE LAST SIXTEEN YEARS.

In order to determine whether it would pay financially to heat an orchard, one must determine how often freezing temperatures are experienced. In other words, we must determine what the frost risk is. We have obtained from the County Agricultural Agents the average dates of the blooming periods of the main fruits for the five largest fruit-producing counties of the state. They are in the order of highest production: Utah, Boxelder, Salt Lake, Weber, and Cache. We have also selected from the reports of the U. S. Weather Bureau, the freezing temperatures that have been experienced by these counties while the fruit is in bloom. These are tabulated below.

If thermograph records had been taken at each place and if they were available, then we could note the time of night when the danger temperature was reached and then heaters would need to burn from then till morning and in this way the approximate number of hours of heating and thus the amount of oil necessary could be determined. Since these are not available for the important fruit sections, we must be content with the minimum temperatures, and we will assume in our calculations that when lighted, on an average, they are kept burning for four hours and that a gallon of oil is consumed in each pot, during the night.

Table V. Number of Times to Heat in Utah County. Taken from Table IV.

	Peaches	Apples
1900	2	0
1901	12	4
1902	5	1
1903	4	0
1904	4	1
1905	4	0
1906	4	1
1907	3	3
1908	5	3
1909	9	5
1910	2	2
1911	15	11
1912	9	5
1913	(Not given)	
1914	1	1
1915	3	2
1916	11	7
Total times to heat in 16 years at Provo	93	46
at Provo Bench	28	13

TABLE IV. Minimum temperatures below 30 deg. F., as reported in the U. S. Weather Reports for Provo, Utah County. (1)

Apples

Peaches

April	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1900	25	..	..	..	..	..	..	..	29	..	26	..	..	..	29	..	29	..	..	..	..	..	..	..	..	..	..	..	..	..
1901	28	22	..	..	22	20	21	26	24	26	..	27	27	..	..	22	19	26	..	..	..	..	..	..	..	..	27	..	..	..
1902	..	..	25	..	..	..	..	..	28	25	..	29	..	..	24	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1903	..	..	..	..	24	24	..	..	..	..	..	20	20	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	28	..
1904	..	..	..	..	29	..	24	25	28	..	..	..	..	..	..	..	..	..	..	..	..	25	..	..	..	..	..	..	..	..
1905	25	..	25	24	26	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1906	..	27	28	27	..	..	..	..	..	..	..	..	24	..	..	..	..	..	..	..	..	..	..	..	..	..	25	..	..	..
1907	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	25	24	28	..	..	29	..	..	..	..	29
1908	24	19	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	27	26	26	..	..
1909	28	..	..	..	..	..	21	20	24	..	..	25	..	..	..	..	..	..	..	..	..	26	26	..	..	..	..	..	..	22
1910	..	..	..	28	..	..	..	..	..	..	..	..	..	26	25	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1911	28	28	..	..	..	..	27	24	..	..	..	27	21	18	16	19	23	23	27	24	..	25	28	..	..	..	..	..	..	..
1912	25	26	29	..	..	25	25	29	..	.	.	..	..	22	23	..	23	..	27	27	28	29	23	..	..	25	..	26	..	..
1913	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1914	29	..	..	..	..	..	..	..	..	..	..	29	..	..	.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1915	27	..	..	..	..	..	..	..	..	..	..	..	..	.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1916	..	..	..	29	..	23	22	23	28	..	..	..	2	[illegible]	.	..	..	..	29	22	..	..	..	..	..	..	..	..	..	28

(1) The key station from which these figures were taken, is at Provo City. The orchards are on the bench and the minimum temperature here is on an average 4 deg. F. warmer than at Provo.

1913—No data available.

TABLE IV. Minimum temperatures below 30 deg. F., as reported in the U. S. Weather Bureau Reports for Provo, Utah County. (1)

Apples

May	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1900	..	..	..	.	..	..	.	..	.	..	..	..	..	..	..	..	..	..	..	..	..
1901	..	..	..	.	..	..	.	..	.	..	..	..	..	..	..	..	..	..	..	..	..
1902	..	..	29	.	28	..	.	..	.	..	..	..	..	..	..	..	..	..	..	..	..
1903	..	..	..	.	..	..	.	..	.	..	..	..	..	..	..	..	..	..	..	..	..
1904	..	.	..	.	..	..	.	29	.	..	..	..	..	..	..	..	..	..	..	..	..
1905	..	..	..	.	..	..	.	..	.	..	..	..	..	..	..	..	..	..	..	..	..
1906	..	..	..	.	..	..	.	..	.	..	..	..	..	..	..	..	..	..	..	..	..
1907	..	..	..	.	..	..	.	..	.	..	..	..	..	..	..	..	..	..	..	..	..
1908	..	..	..	.	..	..	.	..	.	28	..	..	..	..	..	..	..	..	..	..	..
1909	25	..	..	.	..	28	.	..	.	..	..	27	..	29	..	..	..	..	..	..	..
1910	..	..	..	.	..	..	.	..	.	..	..	..	..	..	..	..	..	..	..	..	..
1911	..	..	..	.	..	..	.	..	.	..	26	..	..	..	..	..	..	28	27	..	..
1912	..	..	..	.	..	..	.	..	.	..	..	..	..	..	..	..	..	..	..	..	..
1913	..	..	..	.	..	..	.	..	.	..	..	..	..	..	..	..	..	..	..	..	..
1914	29	..	..	.	26	..	.	..	.	..	..	..	..	..	..	..	..	..	..	..	..
1915	25	26	28	.	..	..	.	..	.	..	..	..	..	..	..	..	..	..	..	..	..
1916	26	..	28	.	..	..	.	..	.	23	29	25	..	23	24	27	..	..	..	..	.

(1) The key station from which these figures were taken, is at Provo City. The orchards are on the bench and the minimum temperature here is on an average 4 deg. F. warmer than at Provo.

1913—No data available.

TABLE VI. Minimum temperatures below 30 deg. F., as reported in the U. S. Weather Bureau Reports for Corinne, Box Elder County. (I)

Peaches

Cherries

Apricots

April	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1901	19	..	28	19	25	24	23	..	..	..	..	..	..	..	..	..	28	..	..	..	..	..	..	..	..	..	..	..	..	..
1902	.	..	..	28	..	..	..	..	..	24	..	28	..	..	27	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1903	..	..	29	29	28	26	..	..	..	29	24	23	25	27	..	..	29	..	..	..	..	..	..	..	..	..	..	..	..	..
1904	27	..	..	..	..	..	26	28	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1905	23	24	..	..	27	..	..	..	..	..	26	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1906	28	29	29	..	..	..	..	..	..	..	..	28	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1907	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	26	29	..	..	29	..	..	29	..	..
1908	22	23	25	28	30	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	29	28	..	..	..
1909	..	..	..	..	..	..	22	22	23	26	22	26	..	..	29	..	..	..	29	..	29	24	27	..	..	..	..	..	..	24
1910	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1911	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1912	27	29	..	..	..	28	29	..	..	..	..	..	..	..	27	..	..	..	29	26	26	26	29	26	29	29	..	..	..	..
1913	..	..	..	..	..	..	..	27	29	26	25	25	26	..	..	..	..	..	..	..	..	..	22	20	..	..	..	..	..	..
1914	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1915	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1916	..	..	..	..	..	29	25	27	..	..	..	28	..	..	..	..	..	..	25	..	..	..	..	..	..	..	..	..	..	..

(1) These temperatures were taken at Corinne because there was a much longer record for that place and probably the temperataures here are slightly lower than at Brigham.

1910-1911. No data available.

TABLE VI. Minimum temperatures below 30 deg. F., as reported in the U. S. Weather Bureau Reports for Corinne, Box Elder County. (1)

Apples

May	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1901	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1902	..	..	..	29	27	..	..	..	..	..	..	..	..	..	..	..	..	..
1903	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1904	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1905	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1906	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1907	..	..	..	..	29	..	..	..	..	..	..	..	..	..	..	..	..	..
1908	..	..	..	..	..	..	..	..	..	29	..	..	..	..	..	..	..	..
1909	24	28	..	..	..	..	..	..	..	..	..	..	..	29	..	..	..	..
1900	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1911	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1912	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1913	..	..	25	28	..	..	..	..	..	..	..	..	..	25	28	..	..	..
1914	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1915	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1916	27	..	..	..	..	..	..	..	..	22	..	..	..	..	24	29	26	25

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(1) These temperatures were taken at Corinne because there was a much longer record for that place and probably the temperatures here are slightly lower than at Brigham.

1910-1911—No data available.

TABLE VIII. Minimum Temperatures below 30 deg. F., as reported in the U. S. Weather Bureau Reports for Salt Lake City. (1)

															Peaches										Apples					
April	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1900	..	..	..	..	..	..	..	24	24	26	..	..	..	26	29	..	..	..	..	..	..	29	..	..	..	..	..	..	..	..
1901	22	29	24	19	21	22	21	20	29	..	..	..	..	..	26	25	24	..	..	..	..	..	..	..	..	..	25	..	..	..
1902	..	..	..	..	..	..	..	..	..	26	..	..	..	..	..	..	..	..	..	..	27	28	..	..	..	..	..	..	..	..
1903	..	27	29	22	20	20	..	..	..	26	22	19	21	..	..	..	..	..	..	..	..	..	..	..	27	..	..	..	..	..
1904	27	..	..	..	29	..	24	26	..	..	..	..	..	..	..	..	..	..	..	28	24	..	..	..	..	..	..	29	27	28
1905	19	28	..	29	..	..	..	..	..	28	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1906	22	22	23	25	25	..	..	..	..	..	..	..	27	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1907	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	28	25	23	29	..	..	..	27	..	..	..	..
1908	19	23	26	..	..	27	26	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	27	..	..	..	..	..
1909	..	..	..	26	20	22	22	23	26	26	27	26	..	..	..	..	..	..	..	29	27	24	29	..	27	27	..	28	..	..
1910	..	28	24	25	28	..	..	..	..	..	..	..	..	28	23	28	..	..	..	..	..	..	..	..	..	..	..	..	23	23
1911	..	..	..	..	..	29	..	..	..	..	29	19	17	21	27	..	..	..	26	25	..	..	..	..	29	..	..	..	..	..
1912	28	..	..	..	..	..	..	..	..	..	..	27	26	26	29	..	..	26	23	21	25	26	27	..	..	..	..	..	..	28
1913	..	26	26	..	..	27	26	27	..	..	..	..	..	..	..	..	..	..	..	..	..	29	24	28	..	..	..	..	..	..
1914	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1915	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	27

(1) These temperatures were taken at the U. S. Weather Bureau Station at Salt Lake City. The temperatures in the orchard districts are on an average lower than these.

TABLE VIII. Minimum Temperatures below 30 deg. F., as reported in the U. S. Weather Bureau Reports for Salt Lake City. (1)

Apples

May	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1900	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1901	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1902	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1903	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1904	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	27	..	..
1905	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1906	..	..	29	..	..	..	..	..	..	28	..	..	..	..	..	..	..	..	..
1907	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	28	..	..
1908	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1919	..	..	..	..	..	..	..	..	..	24	28	..	..	..	..	..	29	..	27
1910	..	25	..	..	..	..	..	..	..	..	..	26	..	..	..	..	..	..	..
1911	..	..	25	28	..	..	..	..	..	..	..	..	..	..	28	..	..	..	..
1912	29	29	28	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1913	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1914	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1915	28	29	27	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..

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(1) These temperatures were taken at the U. S. Weather Bureau Station at Salt Lake City. The temperatures in the orchard districts are on an average lower than these.

TABLE X. Minimum Temperatures below 30 deg. F., as Reported in the U. S. Weather Bureau Reports for Ogden, Weber County. (1)

Peaches

Mch.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
1900	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	28	29	..	..	..
1901	..	..	..	..	..	27	28	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1902	25	..	28	22	26	..	..	..	..	28	..	29	27	18	22	12	22	..	..	27	..	..	28	..	..	..	29	26	18	19	28
1903	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1904	..	29	21	..	25	..	..	..	..	26	29	21	22	..	..	29	..	..	..	..	23	27	..	17	25	24	27	..	..	..	27
1905	..	29	21	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	26	..	..	..	..	26	..	26	16
1906	24	21	21	..	21	25	29	..	..	..	24	..	24	22	23	.8	14	20	18	25	..		..	..	..	27	24	26	..	29	..
1907	..	..	..	..	..	..	..	..	..	..	..	..	27	29	29	..	..	..	..	..	..	26	..	..	..	..	..	25	·24	..	27
1908	27	..	29	..	..	..	.2	19	20	24	26	..	..	..	..	..	..	..	22	27	..	..	..	..	..	..	..	..	..	..	..
1909	29	..	..	..	29	..	..	25	19	27	21	14	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1910	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1911	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1912	27	28	17	13	25	28	29	..	..	..	27	24	18	23	26	..	..	..	28	..	..	..	..	..	..	..	..	..	..	..	..
1913	16	21	21	..	..	..	25	25	26	27	29	20	12	.9	18	..	..	..	..	10	12	25	27	18	12	.5	14	21	..	..	..
1914	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1915	..	..	26	..	25	..	29	29	29	..	..	..	..	..	..	..	..	..	27	29	..	..	..	..	..	..	..	..	..	..	..

(1) These temperatures were taken at Ogden, which does not have as good air drainage as the fruit districts of Weber County.

1903—Month of March cold; buds held back.

1914—No data available.

TABLE X. Minimum Temperatures below 30 deg. F., as reported in the
Weather Bureau Reports for Ogden, We ber County. (1)

Apples

April	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1900	28	..	..	29	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1901	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1902	..	28	29	..	28	24	..	..	..	29	25	22	28	..	..	..	..	..	..
1903	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1904	..	..	..	..	..	..	27	..	..	..	..	..	..	..	..	..	..	..	..
1905	23	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1906	..	27	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1907	20	24	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1908	..	..	..	..	29	28	28	..	..	..	22	..	..	28	..	30	..	26	..
1909	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1910	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1911	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1912	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1913	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1914	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1915	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..

(1). These temperatures were taken at Ogden, which does not have as good air drainage as the fruit districts of Weber County.

1903—Month of March cold; buds held back.
1914—No data available.

TABLE VI. Minimum temperatures below 30 deg. F., as reported in the U. S. Weather Bureau Reports for Corinne, Box Elder County. (I)

Peaches

Cherries

Apricots

April	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1901	19	..	28	19	25	24	23	..	..	..	..	..	..	..	..	..	28	..	..	..	..	..	..	..	..	..	..	..	..	..
1902	.	..	..	28	..	..	..	..	..	24	..	28	..	..	27	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1903	..	..	29	29	28	26	..	..	..	29	24	23	25	27	..	..	29	..	..	..	..	..	..	..	..	..	..	..	..	..
1904	27	..	..	..	..	..	26	28	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1905	23	24	..	..	27	..	..	..	..	..	26	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1906	28	29	29	..	..	..	..	..	..	..	..	28	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1907	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	26	29	..	..	29	..	..	29	..	..
1908	22	23	25	28	30	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	29	28	..	..	..
1909	..	..	..	..	..	..	22	22	23	26	22	26	..	..	29	..	..	..	29	..	29	24	27	..	..	..	..	..	..	24
1910	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1911	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1912	27	29	..	..	..	28	29	..	..	..	..	..	..	..	27	..	..	..	29	26	26	26	29	26	29	29	..	..	..	..
1913	..	..	..	..	..	..	..	27	29	26	25	25	26	..	..	..	..	..	..	..	..	..	22	20	..	..	..	..	..	..
1914	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1915	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1916	..	..	..	..	..	29	25	27	..	..	..	28	..	..	..	..	..	..	25	..	..	..	..	..	..	..	..	..	..	..

(1) These temperatures were taken at Corinne because there was a much longer record for that place and probably the temperataures here are slightly lower than at Brigham.
1910-1911—No data available.

TABLE VI. Minimum temperatures below 30 deg. F., as reported in the U. S. Weather Bureau Reports for Corinne, Box Elder County. (1)

Apples

May	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1901	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1902	..	..	..	29	27	..	..	..	..	..	..	..	..	..	..	..	..	..
1903	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1904	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1905	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1906	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1907	..	..	..	..	29	..	..	..	..	..	..	..	..	..	..	..	..	..
1908	..	..	..	..	..	..	..	..	..	29	..	..	..	..	..	..	..	..
1909	24	28	..	..	..	..	..	..	..	..	..	..	..	29	..	..	..	..
1900	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1911	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1912	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1913	..	..	25	28	..	..	..	..	..	..	..	..	..	25	28	..	..	..
1914	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1915	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1916	27	..	..	..	..	..	..	..	..	22	..	..	..	..	24	29	26	25

(1) These temperatures were taken at Corinne because there was a much longer record for that place and probably the temperatures here are slightly lower than at Brigham.

1910-1911—No data available.

TABLE VIII. Minimum Temperatures below 30 deg. F., as reported in the U. S. Weather Bureau Reports for Salt Lake City. (1)

Apples

Peaches

April	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1900	..	..	..	..	..	..	..	24	24	26	..	..	..	26	29	..	..	..	..	..	..	29	..	..	..	..	..	..	..	..
1901	22	29	24	19	21	22	21	20	29	..	..	..	..	..	26	25	24	..	..	..	..	..	..	..	..	..	25	..	..	..
1902	..	..	..	..	..	..	..	..	..	26	..	..	..	..	..	..	..	..	..	..	27	28	..	..	..	..	..	..	..	..
1903	..	27	29	22	20	20	..	..	..	26	22	19	21	..	..	..	..	..	..	..	..	..	..	..	27	..	..	..	..	..
1904	27	..	..	..	29	..	24	26	..	..	..	..	..	..	..	..	..	..	..	28	24	..	..	..	..	..	..	29	27	28
1905	19	28	..	29	..	..	..	..	..	28	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1906	22	22	23	25	25	..	..	..	..	..	..	..	27	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1907	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	28	25	23	29	..	..	..	27	..	..	..	..
1908	19	23	26	..	..	27	26	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	27	..	..	..	..	..
1909	..	..	..	26	20	22	22	23	26	26	27	26	..	..	..	..	..	..	..	29	27	24	29	..	27	27	..	28	..	..
1910	..	28	24	25	28	..	..	..	..	..	..	..	..	28	23	28	..	..	..	..	..	..	..	..	..	..	..	..	23	23
1911	..	..	..	..	..	29	..	..	..	..	29	19	17	21	27	..	..	..	26	25	..	..	..	..	29	..	..	..	..	..
1912	28	..	..	..	..	..	..	..	..	..	..	27	26	26	29	..	..	26	23	21	25	26	27	..	..	..	..	..	..	28
1913	..	26	26	..	..	27	26	27	..	..	..	..	..	..	..	..	..	..	..	..	..	29	24	28	..	..	..	..	..	..
1914	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1915	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	27

(1) These temperatures were taken at the U. S. Weather Bureau Station at Salt Lake City. The temperatures in the orchard districts are on an average lower than these.

TABLE VIII. Minimum Temperatures below 30 deg. F., as reported in the U. S. Weather Bureau Reports for Salt Lake City. (1)

Apples

May	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1900	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1901	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1902	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1903	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1904	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	27	..	..
1905	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1906	..	..	29	..	..	..	..	..	..	28	..	..	..	..	..	..	..	..	..
1907	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	28	..	..
1908	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1919	..	..	..	..	..	..	..	..	..	24	28	..	..	..	..	..	29	..	27
1910	..	25	..	..	..	..	..	..	..	..	..	26	..	..	..	..	..	..	..
1911	..	..	25	28	..	..	..	..	..	..	..	..	..	..	28	..	..	..	..
1912	29	29	28	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1913	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1914	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1915	28	29	27	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..

(1) These temperatures were taken at the U. S. Weather Bureau Station at Salt Lake City. The temperatures in the orchard districts are on an average lower than these.

TABLE X. Minimum Temperatures below 30 deg. F., as Reported in the U. S. Weather Bureau Reports for Ogden, Weber County. (1)

Peaches

Mch.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
1900	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	28	29	..	..	..
1901	..	..	..	..	..	27	28	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1902	25	..	28	22	26	..	..	..	..	28	..	29	27	18	22	12	22	..	..	27	..	..	28	..	..	..	29	26	18	19	28
1903	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1904	..	29	21	..	25	..	..	..	..	26	29	21	22	..	..	29	..	..	..	..	23	27	..	17	25	24	27	..	..	..	27
1905	..	29	21	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	26	..	..	..	..	26	..	26	16
1906	24	21	21	..	21	25	29	..	..	..	24	..	24	22	23	.8	14	20	18	25	..		..	..	..	27	24	26	..	29	..
1907	..	..	..	..	..	..	..	..	..	..	..	..	27	29	29	..	..	..	..	..	..	26	..	..	..	..	..	25	24	..	27
1908	27	..	29	..	..	..	.2	19	20	24	26	..	..	..	..	..	..	..	22	27	..	..	..	..	..	..	..	..	..	..	..
1909	29	..	..	..	29	..	..	25	19	27	21	14	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1910	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1911	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1912	27	28	17	13	25	28	29	..	..	..	27	24	18	23	26	..	..	..	28	..	..	..	..	..	..	..	..	..	..	..	..
1913	16	21	21	..	..	..	25	25	26	27	29	20	12	.9	18	..	..	..	..	10	12	25	27	18	12	.5	14	21	..	..	..
1914	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1915	..	..	26	..	25	..	29	29	29	..	..	..	..	..	..	.	..	..	27	29	..	..	..	..	..	..	..	..	..	..	..

(1) These temperatures were taken at Ogden, which does not have as good air drainage as the fruit districts of Weber County.

1903—Month of March cold; buds held back.
1914—No data available.

TABLE X. Minimum Temperatures below 30 deg. F., as reported in the U. S. Weather Bureau Reports for Ogden, Weber County. (1)

Apples

April	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1900	28	..	..	29	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1901	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1902	..	28	29	..	28	24	..	..	..	29	25	22	28	..	..	..	..	..	..
1903	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1904	..	..	..	..	..	..	27	..	..	..	..	..	..	..	..	..	..	..	..
1905	23	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1906	..	27	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1907	20	24	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1908	..	..	..	..	29	28	28	..	..	..	22	..	..	28	..	30	..	26	..
1909	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1910	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1911	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1912	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1913	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1914	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1915	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..

(1). These temperatures were taken at Ogden, which does not have as good air drainage as the fruit districts of Weber County.

1903—Month of March cold; buds held back.
1914—No data available.

TABLE XII. Minimum Temperatures below 30 deg. F., as Reported in the U. S. Weather Bureau Reports for Logan, Cache County. (1)

													Peaches									
April	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1900	29	26	..	..	..	..	29	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1901	25	22	..	..	..	..	..	..	28	28	..	..	..	..	..	..	..	..	..	..	..	..	..
1902	..	..	26	..	..	27	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1903	..	..	..	..	20	20	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	28	..
1904	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1905	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1906	..	..	..	..	..	28	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1907	..	..	..	..	..	..	..	16	..	..	..	29	28	27	..	..	..	..	..	..	..	..	..
1908	..	..	..	..	..	..	..	..	..	..	..	..	..	..	23	23	..	..	..	..	..	..	..
1909	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1910	..	..	..	..	..	..	..	25	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1911	..	..	..	..	24	17	19	27	..	..	..	28	29	..	29	..	..	..	..	..	..	..	..
1912	..	..	..	..	..	..	29	..	..	..	..	26	23	..	27	..	..	..	..	..	..	..	..
1913	28	29	29	..	..	..	..	..	..	..	..	..	..	..	..	24	..	..	..	..	..	..	29
1914	28	26	29	26	28	..	..	..	27	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1915	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1916	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..

(1). The most important orchard districts in Cache Valley have about the same air drainage as the area near the key station and as shown by a survey have about the same temperatures.

1909—No data available.

TABLE XII. Minimum Temperatures below 30 deg. F., as Reported in the U. S. Weather Bureau Reports for Logan, Cache County. (1)

	Peaches						Apples											
May	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1900	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1901	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1902	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1903	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1904	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1905	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1906	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1907	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1908	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1909	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1910	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1911	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1912	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1913	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1914	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1915	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1916	..	..	..	..	..	..	..	..	..	16	22	..	28	29	29	..	..	..

(1). The most important orchard districts in Cache Valley have about the same air drainage as the area near the key station and as shown by a survey have about the same temperatures.

1909—No data available.

Table VII. Number of Times to Heat at Corinne, Box Elder County, taken from Table VI.

	Apricoats	Peaches	Cherries	Apples
1901	5	0	0	0
1902	3	0	0	0
1903	4	4	4	0
1904	1	1	0	0
1905	2	0	0	0
1906	0	0	0	0
1907	0	0	0	0
1908	3	0	0	0
1909	9	9	3	0
1910 (not given)				
1911 (not given)				
1912	5	5	5	2
1913	7	7	4	2
1914	0	0	0	0
1915	0	0	0	0
1916	6	6	5	4
Total heatings 14 years	45	32	21	8

Table IX. Number of Times to Heat in Salt Lake, Salt Lake County, as taken from Table VIII.

	Peaches	Apples
1900	0	0
1901	4	1
1902	1	0
1903	3	3
1904	1	0
1905	0	0
1906	0	0
1907	3	0
1908	4	2
1909	6	4
1910	0	0
1911	2	0
1912	7	1
1913	3	2
1914	0	0
1915	2	2
Total heatings in 16 years	36	15

Table XI. Number of Times to Heat for Peaches and Apples, Weber County, as taken from Table X.

Year	Peaches	Apples
1900	0	0
1901	0	0
1902	7	0
1903	4	0
1904	9	0
1905	5	0
1906	10	0
1907	4	0
1908	8	0
1909	4	4
1910	not given	not given
1911	not given	not given
1912	5	0
1913	9	0
1914	not given	not given
1915	1	0
Total Heatings in 13 Years	66	4

Table XIII. Number of Times to Heat Peaches and Apples in Cache County as taken from Table XII.

Year	Peaches	Apples
1900	0	0
1901	0	0
1902	0	0
1903	1	0
1904	0	0
1905	0	0
1906	0	0
1907	0	0
1908	2	0
1909	not given	not given
1910	0	0
1911	1	0
1912	0	0
1913	1	0
1914	0	0
1915	0	0
1916	3	3
Total Heatings in 16 Years	8	3

Near the top of the tables, the word "apples" is written and underneath it is drawn a line about one-fourth as long as the table is wide. Underneath the left end of the line will be found the average date that the apples begin to bloom in this particular county and underneath the right end of the line will be found the average date the petals have fallen and the fruit is setting. The same explanation hold for the other kinds of fruit listed.

Where a figure in the table is underscored once, it means that in our judgment a peach orchard in that county should have been heated on that night. If a figure is underscored twice, an apple orchard should have been heated. The basis of our selection of these dates and of our estimation from these of the total number of times that heating should have been done to prevent loss from frost is this: It has been our experience that the buds in their early stages can stand one or two freezes of 25° F. to 27° F. and there will still be enough buds left to give a satisfactory crop, but when a third frost occurs the heaters should be lighted. A cautious orchardist would heat considerably oftener than we have indicated because on some of the nights of early spring where we counted on not heating, it being the first freeze and of 26 deg. F. only, he may have heated because of expecting a lower temperature. It has been the experience of most of the workers in the field that it is much easier to hold the temperature just above the critical point than it is to raise it to that point after it has cooled; hence as a matter of safety and to be conservative they have uniformly advocated lighting the fires early. The figures therefore represent our judgment as to the least number of times that the heaters should have been lighted.

It has been found by this station that none of the fruit is injured by a temperature of 20 deg. F., for which reason only temperatures lower than this were placed in the tables.

DOES ORCHARD HEATING PAY IN UTAH?

A study of the temperature tables Nos. IV to XIII shows that on an average in the five most important horticultural counties in the state, heating is necessary at least three times a year to save the peach crop. We found by gathering data from the farmers in these counties ourselves as well as from the data collected by County Agricultural Agents that farmers lose on an average of ten years over twenty per cent of their crops and that the average normal yield is 400 bushels of peaches to the acre. This means then that they lose on an average 80 bushels of peaches a year. The average price received by the farmers after picking and packing is approximately $ .55 and the average cost of picking and packing is $ .20. The value of each bushel of peaches saved would then be $ .35 and the value of the 80 bushels saved on each acre would be $28. But let us see what it would cost to save this. Figuring oil at $ .09 a gallon, allowing 100 gallons per acre, figuring that one man can tend ten acres, and that the heating is done only on nights when it is absolutely necessary and not to ward off light frosts that only thin the buds, and figuring the overhead expense each year the same as we have on page 18, it would cost $50.50 or more to save the crop. In other words it costs $50 to save $28 worth of fruit.

Taking the average normal yield of apples as 450 bushels and the average price received for them as $ .75 a bushel after being picked and packed or $ .55 on the trees, let us see if the farmers can make money by heating when they lose twenty per cent of their crop each year. They lose 90 bushels every year which amounts to $49.50. From a study of tables again we judge that apples would be heated on an average of at least two nights a year, which would cost $50.

Inasmuch as the heating may fail because of accidents such as an inaccurate forecast, or the temperature might be so very low or wind so high that the heating was insufficient to warm the buds above the danger temperature, or the extra help might fail and both the crop and the oil be lost in addition to the extra worry of handling the heating business undertaken that it is very doubtful whether heating should be resorted to in Utah at all. At best and with the least number of times of heating that are necessary, the crop is only worth approximately the cost of heating. In Utah it would be very difficult to heat because the orchards are so scattered.

If the locality is such that heating is justifiable, then it is very certain that if it is resorted to it must be done with care and precision according to the most approved methods with plenty of heaters and plenty of help, taking care that no fuel is wasted.

Weather bureau forecasts are usually very conservative, i. e., they will not miss reporting a severe frost but they sometimes report a light frost that turns out to be harmless and the hired men that have been summoned to help with the firing have to be paid even tho it was not cold enough to justify lighting up. The more frequent the occurrence of frost, the greater is the loss of fruit, but the greater would be the expense of heating; so that for crops of the value we have assumed and at the expense of heating we have given, heating is of doubtful economic value anywhere in the state. (Higher prices usually exist after a freeze because of scarcity of fruit.)

In California, where it is reported to be a financial success, the frosts usually occur without heavy winds and the high value of the orange or lemon crop makes the cost of heating small in comparison to it. There they also heat to protect the trees from freezing.

CONDITIONS UNDER WHICH ORCHARD HEATING PAYS

The experience of orchard men in California seems to show that if farmers are willing to pay the price, they can ward off the effects of many and severe frosts. If they use intelligence and care, having wind breaks, plenty of oil, labor, and heaters in place, accurate thermometers, and accurate forecasts of the weather together with careful organization and cooperation through many neighboring farmers heating simultaneously, there is little doubt that the fruit can successfully be protected from severe frosts. It is doubtful whether fruit can be protected against freezes caused by north winds of 10 miles an hour or more.

In the following discussion we are going to give the benefit of the doubt in each case to the side of the heating and when we talk of the number of nights of heating we shall assume that the earlier nights when light frosts have simply thinned the buds, are omitted and only on the nights when the frost would actually cut down the final yield in the fall that the heaters would be lighted.

In calculating the cost of heating an orchard we must not only consider the cost of oil and labor for the night and the cost of placing the pots in the orchard, filling, and gathering them again each year, but we must add to this the interest and depreciation on the orchard heating equipment. We have calculated the interest and depreciation per acre per year as follows:

INTEREST ON EQUIPMENT FOR TEN ACRES

1500 heaters @ $ .20	$300.00
1 wagon @ $60.00	60.00
Torches	10.00
Thermometers	15.00
Storage Tank	240.00

For ten acres	$625.00
For one acre	62.50
Interest at 8%	5.00

DEPRECIATION ON ABOVE EQUIPMENT

Heaters	$ 30.00
Wagon	4.00
Torches	1.00
Thermometers	1.50
Tank	12.00

For ten acres	$48.50	
For one acre	4.85	
Interest		5.00
Depreciation		4.85
Placing		7.00
Clothes		5.00
		$ 21.85

Each year the heaters must be placed in the orchard and then after the fruit has developed past the danger point they must be emptied and gathered and cleaned. There is also the cost of the clothes the two men wear while handling this oil for these clothes are ruined. Since these are constant overhead expenses we will add them to the interest and depreciation factor used in later equations. In Utah the placing, etc., costs about $7 and the clothes injury $5. These two added to the interest and depreciation make the total overhead cost $21.85.

In working out the equations that follow we have used the round number of $22.00 for the total constant overhead expense.

The total receipts from fruit must exceed cost of production by enough to pay a reasonable interest on the investment in the farm. Let us examine this mathematically.

Whether one should heat or not depends on cost of labor, cost of fuel, price of fruit, etc.; under some conditions it will pay, while under others it will not. The only way to tell is by the following very simple mathematical analysis which is fully and clearly explained in words as it is developed. From a study of this and the numerous examples and graphs worked out, one should be able to tell in any locality by the same reasoning whether he should heat or not.

Expressing these factors mathematically—let P stand for the money invested in the land, buildings, machinery, etc.

Let "I" represent the interest rate at which money can be borrowed.

Let "i" be the interest above I i. e., if a business man borrowed money at 8% and bought an orchard, paid some one to run it and made a profit of 10% then after he has paid his 8%, he has made 2 per cent. "I" in this case would be 8 per cent and "i" would be 2 per cent. He should make something because he is taking a risk of going behind. Many farmers consider their place as a home (against which interest should not be charged) which gives employment to themselves and children and do not expect more than two to six percent on the value of the place.

Let "b"= the number of boxes of fruit obtained per acre.

Let "s"= the selling price per box or what the farmer gets per box when the fruit is picked and packed.

Let "k"= the price of picking and packing a box of fruit to cars.

Let "c"= the cost of producing an acre of fruit except picking and packing and the interest on the investment and includes,

Maintenance Costs

- Manuring
- Cultivators
- Pruning
- Brush Handling
- Irrigation
- Thinning
- Propping
- Spraying
- Cover Crop
- Miscellaneous Labor

Material Costs

- Spraying
- Manure
- Gasoline and oil

Fixed Costs

- Taxes
- Water tax
- Insurance
- Equipment charge
- Packing house charge

Let “n”= the number of nights a year that the orchard is heated.

Let “g”= the number of gallons of oil burned a night on an acre.

Let “r”= the cost of oil per gallon.

Let “L”= the cost of labor for heating one acre for one night.

Let “Dh”= the over head cost and includes the interest and depreciation on the heating equipment, the cost of placing, filling with oil, and gathering up again as well as cost of clothes of workmen.

Using the above notation we derive the following equation:

$$b(s-k)-c-n(g\,r+L)-Dh-IP=iP \qquad (1)$$

Solving for “s” in this equation we obtained:

$$s=\frac{bk+c+n(gr+L)+Dh+IP+iP}{b} \qquad (2)$$

An example will make it clear. Using typical Utah data for an apple orchard and considering the labor (L) as 2 men at \$2.50 a night for ten acres or 50 cents per acre and a consumption of 100 gallons of oil an acre, the equation becomes:

$$s=\frac{400\times.20+50+6(100\times.09+.50)+22+.04\times300}{400} \text{ or } s=\$0.55$$

i. e. considering the yield (b) as 400 bushels of apples a year, the cost of picking and packing a box (k) as 20c, the cost of producing the yield on an acre (c) as \$50, the number of nights you must heat the orchard a year (n) as 6, the cost of oil (r) as 9c (a gallon) interest on the money invested (I) 4%, then in order to be able to do this you must get at least 50c a box for your apples after they are picked.

This equation says in words that if you subtract from the amount of money that you receive for the sale of the fruit, the entire cost of producing it, including the cost of heating the orchard and the interest cost on the investment, what you will have left will be profit. If the yield and selling price are high, while the amount of money invested and cost of production are low then you will of course make a large profit. In a section where frost diminishes the yield of fruit and by heating the yield is raised to the normal value, then heating must be reckoned as part of the cost of production. If when the interest on the money value of the farm and equipment and the remaining cost of production is subtracted from the amount of money received from the crop during a normal yield, there will be no money left to do the heating during the years when a small yield is obtained because of frosts, then instead of buying heating equipment one should go out of this particular kind of farming or else by better management cut down the cost of production.

Solving for "n" in the above equation (1) we obtain:

$$n=\frac{b\,(s-k-c-Dh-P(I+i)}{(g\ r+L)} \qquad (3)$$

which shows that if the amount of money left over after all the costs of production except heating have been paid is considerable and if the cost of heating one night is small because of cheap labor and oil, then one can afford to heat several nights, i. e. to be able to heat, you must get a high price for the fruit, the cost of production must be small, including interest on the principal so that there will be money left over to spend on the heating and you must be able to get the fuel cheaply. Although in equation (1) the cost fo heating is a subtractive factor and appears to cut down the profits by increasing the cost of production, yet we shall show later in this paper that it will either increase or decrease the profits depending on whether the value of the fruit that is saved by the heating is more than the cost of the heating. Of course, if there be two orchards where everything else is the same (same labor cost, same investment, etc.) the only difference being that one experiences killing frosts while the other does not, it is obvious that the one where heating has to be resorted to will make less profits.

We might have two different farms where the one that experienced killing frosts and had to increase his cost of production by heating had less money tied up in the farm and his farm is close to the market and his other costs of production were sufficiently low that his entire cost of production including the heating cost was as low as that of the farmer who does not have to heat his orchard. He could then resort to orchard heating and compete with the other farmer.

Let us examine this proposition mathematically.

Let the subscript "$_1$" stand for the farm where frost does not occur and "$_2$" for the one where it does occur.

Let us assume that in the two localities the farmers are equally well organized and their product is equally good and equally advertised so that $s_1=s_2$ and that the heating saves the entire crop so that $b_1=b_2$ also that the picking and packing cost is the same making $k_1=k_2$ also that the interest rate on their money and the profits in per cent are to be the same.

Then with $s_1=s_2$, $b_1=b_2$, $k_1=k_2$, $1_1=1_2$, and $i_1=i_2$, we get the following equation when they are substituted in equation (1)

$b_1\ (s_1-k_1)-c_1-I_1\ P_1=i_1P_1$ where there is no frost and although $n=0$, the other costs must be correspondingly higher and for the farm where heating has to be resorted to we obtain $b_1\ (s_1-k_1)-c_2-n\ (gr+L)-Dh-I_1\ P_2=iP_2$. Subtracting the second equation from the one above it gives:

$c_2-c_1+n(gr+L)+Dh-I(P_1-P_2)=i(P_1-P_2)$. Solving for "n" we obtain

$$n=\frac{c_1-c_2+(P_1-P_2)\ (I_1+i_1)-Dh.}{(gr+L)} \qquad (4)$$

This shows that if there is a large difference in general cost of production and in total investment and that if the cost of heating one night is small, then the man who heats can afford to heat a considerable number of nights and still compete with the man who is in the frost-free locality. Let us examine a specific case.

Let $\$75=c_1$ and $\$50=c_2$
Let $\$22=Dh$
Let $\$400=P_1$ and $\$200=P_2$
Let $I=.08$ and $i=0$

$$\text{Then } n=\frac{75-50\ (400-200)\ .04-22.}{100x.09+2.} \qquad n=L$$

In other words with two farms valued at \$400 and \$200 an acre and the cost of production \$75 and \$50 an acre, the one with the smaller cost of production and the cheaper land could afford to heat his orchard once a year and make the same profits as the farmer who is in a frost-free location.

The amount of work a farmer can do and the amount of money he can spend on his orchard and still make money will obviously depend upon the price he can get for his fruit. In the following table we have used equation No. 1 and solved for "s" where "s" is the price which must be received for the apples in order to fill the other conditions given in the table.

The data used were taken from government surveys of the cost of producing apples in Wenatchee Valley, Washington, Hood River, Oregon, and Western Colorado, and which are reported in U. S. D. A. Bulletins Nos. 446, 518 and 500 respectively. The data for Utah are for average estimates given by horticultural men of the State.

Table No. 14.—Selling price of apples in order to obtain 0, 4 and 8 per cent interest on investment with or without heating for different localities.

State	Boxes	Principal	Cost	Dh.	Interest	Number of Times to Heat	Selling Price Per Bu.	Cost to Pick and Pack
Colorado	284	$ 751.00	$199.00	$22	0 per cent	0	$ .97	$0.28
Colorado	284	751.00	199.00	22	4 per cent	0	1.07	.28
Colorado	284	751.00	199.00	22	8 per cent	0	1.19	.28
Colorado	284	751.00	199.00	22	8 per cent	3	1.37	.28
Colorado	284	751.00	199.00	22	8 per cent	6	1.47	.28
Hood River	222	990.00	180.00	22	0 per cent	0	1.09	.28
Hood River	222	990.00	180.00	22	4 per cent	0	1.27	.28
Hood River	222	990.00	180.00	22	8 per cent	0	1.64	.28
Hood River	222	990.00	180.00	22	8 per cent	3	1.67	.28
Hood River	222	990.00	180.00	22	8 per cent	6	1.80	.28
Wenatchee Valley	592	1,925.00	376.73	22	0 per cent	0	.79	.32
Wenatchee Valley	592	1,925.00	376.73	22	4 per cent	0	.92	.32
Wenatchee Valley	592	1,925.00	376.73	22	8 per cent	0	1.05	.32
Wenatchee Valley	592	1,925.00	376.73	22	8 per cent	3	1.13	.32
Wenatchee Valley	592	1,925.00	376.73	22	8 per cent	6	1.18	.32
Utah	450	300.00	75.00	22	0 per cent	0	.37	.20
Utah	450	300.00	75.00	22	4 per cent	0	.39	.20
Utah	450	300.00	75.00	22	8 per cent	0	.42	.20
Utah	450	300.00	75.00	22	8 per cent	3	.53	.20
Utah	450	300.00	75.00	22	8 per cent	6	.60	.20

From this table it is seen that in Western Colorado, in order to make 8 per cent on the investment after paying for heating 3 nights a year, the farmer must receive $1.37 a bushel for his apples; in Hood River $1.67, and in Utah $0.53, while without heating these figures would be $1.19, $1.64 and $0.42 a bushel.

In some localities, one farmer is heating his orchard while his neighbor is not. Each thinks that he is doing right and that his way is the better. Let us examine this case! We will not at present decide if they should be in the business or not, but simply, if they are both making money which is making more, or if both are losing, which is losing less.

We will assume that the farmer knows how to heat, that he is careful, has plenty of oil pots, accurate weather forecasts and no accidents, i. e. that when he heats it is always necessary and that he always saves his crop. We will first examine the case where the frost takes part of the crop each year.

Using equation No. 1 for the man who heats we have:

$B(s-k)-c-n(gr+L)-Dh-IP=iP$ (1)

When no heating is done the equation becomes:

$b(s-k)-c-IP=i_2P.$ (5)

We are assuming that $s_1=s_2$, $k_1=k_2$, $c_1=c_2$, $p_1=P_2$, $I_1=I_2$ i. e. farms are exactly alike except that $B>b$ or the one that heats gets more fruit and that $i_1>i_2$ i. e. that the profits are different

Subtracting equation (5) from (1) gives:

$B(s-k)-c-b(s-k)+c-n(gr+L)-Dh=(i_1-i_2)P$

To make it pay to heat i_1 must be larger than i_2 and this will make the right side of the equation positive and hence the left side must also be positive. For the left side to be positive

$Bs-Bk-bs+bk>n(gr+L)+Dh$ or $s(B-b)-k(B-b)>n(gr+L)+Dh$

Let $B-b=\triangle b$ then we obtain by substitution:

$\triangle b(s-k)>n(gr+L)+Dh.$ (6)

This equation means that in order for the farmer who heats to make more money than his neighbor who does not, everything else being exactly the same, the value of the excess of his crop over the others without being picked must be more than the entire cost of heating that year.

In examining this equation further let us assume that the man who heats makes the same profits as the one who does not for the purpose of noting the relation between the variables and we will write = instead of >, which will give us

$$\triangle b(s-k)=n(GR+L)+Dh$$

Solving for n gives us $n=\dfrac{\triangle b(s-k)-Dh.}{(gr+L)}$

which shows that the man can afford to heat many times and yet break even with the one who does not if he gets much more fruit than the other, (the other lost fruit by frost) if the selling price of the fruit is large and if the cost of heating one night is small because of cheap oil and labor. With the same excess of fruit if he can heat a less number of times, then he is ahead of the other fellow financially.

The equation may also be written in this form:

$$n=\frac{\triangle b\ (s-k)}{gr+L}-\frac{Dh}{gr+L}$$

the plot of which is a straight line with $(s-k)\ /\ gr+L$ as the slope and $-Dh\ /\ gr+L$ as intercept, n and b being the variables.

Using the following figures for the constants:

s=\$0.90 k=\$0.14 Dh=\$22

r=\$0.09 2 men at \$2.50=\$5 for L a night, and considering 100 heaters burning a gallon of oil during the night gives

$$n = \frac{\triangle b \;(\,.90 - .14)}{100\text{x}\ .09+5} - \frac{22}{100\text{x}\ .09+5}$$

$$n = .054\,b - 1.57 \qquad (7)$$

This result is shown graphically in curve No. 1 of Figure 2, the amount of fruit saved by heating increasing as the number of nights of heating increases, and where the number is large the one nearly varies directly as the other; e. g., where b=300, we get n=300x.054—1.57 or n=16.2—1.57, the latter term being less than one-tenth of the former.

Curve No. 1 shows graphically the relation between the amount of fruit saved by heating, and the number of times heating is resorted to during the year and is the plot of equation No. 7 considering the cost of oil as constant and as \$.09 the figure quoted by the Standard Oil Company, f. o. b. Logan, and considering the selling price of the fruit as constant and as \$.90 a box. It shows that as the number of nights that the frost occurs increases, the amount of fruit obtained by the farmer in excess of that obtained by the man who doesn't heat, i. e., the amount saved must increase. Unless he can actually heat a less number of times than this and save this amount of fruit he will not be financially ahead of the man who doesn't heat. This relation, although established on the basis of money relations, represents about what happens climatically because each frost in the spring of the same degree kills approximately the same per cent of the buds and the more nights of frost the less the yield of fruit in the fall and the more nights that heating has to be resorted to. If, therefore, considerable frost is experienced so that Dh is small in comparison to the other factors, the question as to whether one should heat his orchard or not is not a function of whether there is much or little frost. In other words, a man in one locality might have to heat five nights to save his crop while the other man in the same locality lost 25 per cent because of not heating, and in another locality a farmer heated ten nights at twice the cost and saved 50 per cent of the crop while the one here who didn't heat lost 50 per cent and yet the value of the 50 per cent saved might be the same as the cost of the ten nights of heating and the value of 25 per cent of the crop might be

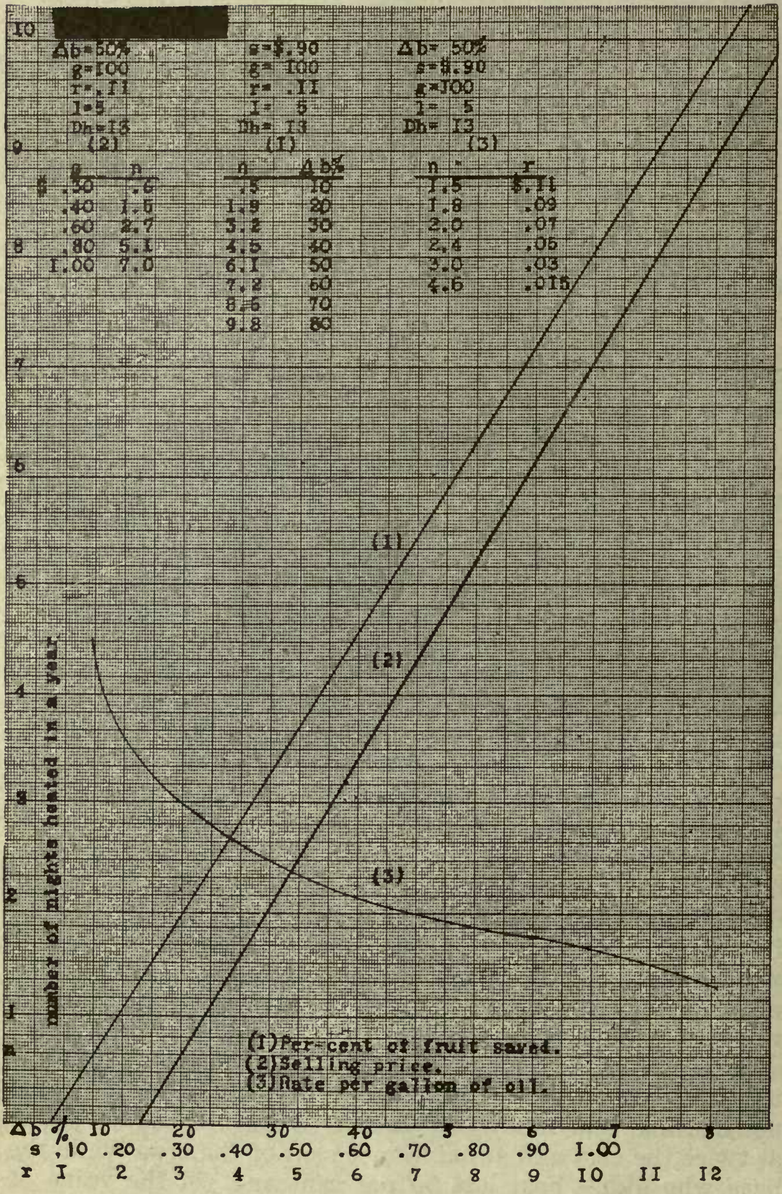

Figure 2.—Curves showing the way the number of nights that the farmer can afford to heat his orchard, changes with: 1, the per cent of the crop that the heating is to save; 2, the selling price of the fruit, and, 3, the cost of the oil a gallon.

equal to the cost of heating five nights, in which case all would break even, although of course the man who heated had the worry and the chance of losing oil and crop due to accident in heating such as too heavy wind, etc. In all cases the value of the crop on the tree saved must be more than the cost of the heating in order for it to pay to be in the heating business and whether one should be heating or not is not a function of the amount of frost that occurs. All other things being the same, and considering the overhead expense of heating as small in comparison with the fuel and labor cost, if it is wisdom to heat an orchard in the south where frost seldom occurs, it will be wisdom to heat in the north where it occurs frequently.

It is also interesting to note that whether one should heat or not, i. e., considering only who is making or losing more money, is not a function of the amount of money invested for P does not occur in the equation Of course if you are heating to save the trees from being killed then an orange tree is worth more than a peach tree and a difference would come in, but we are here simply considering the crop. Heating is more apt to be advisable in California than in other localities because fuel is cheap there and the lemon and orange crop are more valuable than the average apple crop.

Curve No. 2, Figure 2, shows that as the selling price of the fruit goes up the number of times that you can heat and yet compete with the fellow who doesn't, increases, and curve No. 3, Figure 2, shows that as the price of oil goes down the number of times that you can heat, goes up and still break even with the man who doesn't and if you actually heat a less number of times than this and yet save the crop then you are ahead of the one who doesn't heat and you should be in the heating business. However, if you are in the heating business because of reasoning such as the above, you must add this heating cost to the other entire cost of production and if it is now more than what you receive for the fruit then you should go out of the orchard business. If, as was explained earlier, your land values and your other cost of production are low so that you can afford to increase your cost of production by heating and still compete with the frostless locality and if when you spend your money for heating this cost of heating is less than the value of the fruit that you save, then you can compete with the fellow in your locality who doesn't heat and also compete with the frostless locality and win.

After examining the case where the frost takes part of the crop each year let us test the case where the frost takes the entire crop every few years. Let us assume that the frost takes the crop one year out of every three when no heating is done. The orchard heating equipment depreciates at about the same rate whether it is being used or not, so that the interest and depreciation during the life of the equipment must be charged up to heating during the years when heating is done. Therefore, if heating is done every third year, three years' interest and depreciation will have to be charged up to that year. The equation for the man who heats then is:

$$b(s-k)-c-n(gr+L)-3Dh-IP=iP \qquad (8)$$

and for the man who does not heat the equation is:

$$O(s-k)-c-IP=i_1P \qquad (9)$$

This year the man without a crop has to care for the orchard exactly as if he had a crop so that $c=c$ and $P=P$, and $I=I$, but $i>i_1$. Subtracting (9) from (8) we obtain:

$$b(s-k)-o(gr+L)-3Dh=P(i-i_1)$$

In order to make it pay to heat, i must be larger than i_1, which makes the right side of the equation positive and the left side will be positive when

$$b(s-k)>n(gr+L)+3Dh$$

It is to be observed that this equation is just the same as the one developed for the case where part of the crop is destroyed each year except that the interest and depreciation for the years when there is no frost is all charged up against the years when there is frost so that the yield of fruit saved must more than pay for the entire heating cost. The farmer cannot tell ahead of time whether he is going to have frost that year; hence, he will put his heaters in the orchard and fill them and put them up again every year whether there is frost that year or not, and the man who loses his entire crop through not heating will have to take care of the orchard just the same as the man who has a crop on the trees unless it be in the single exception of the spraying so that as far as the economics is concerned this case is just the same as the one just considered. Here b is the entire crop and equals Δb of the other equation.

In the above financial consideration of orchard heating we have assumed that heating never failed to save the crop. However, to have this true the orchard must be protected from winds and the plan of procedure must be worked out to a nicety before the time comes to heat so that there will be no accidents with labor, etc., because if labor is hired and oil is burned the crop must be saved to pay for these. Unless the horticultural business is on a prosperous basis and a thorough preparation is made and carried out orchard heating will not be profitable.

SUMMARY

1. Approximately one-fifth, or twenty per cent, of the fruit on Utah farms is destroyed and considerable damage is done to general farm crops by frosts.

2. In the case of fruit, elimination of this waste has been attempted by delaying the time of flowering until the danger of frost was over, by soil treatments such as irrigating, sanding, and cultivating, by smudging with smoke, water vapor, and carbon dioxide, or by covering the plants or trees with cloth or straw. The most important method is by applying heat and smudge simultaneously through burning coal or oil in the orchard.

3. Professor Cox of the U. S. Weather Bureau has shown that by decreasing the heat capacity of the cranberry bogs of Wisconsin through draining, sanding and cultivating, the minimum temperature of the air directly above the ground was 7° F. higher than that over the untreated bogs. This difference in temperature disappeared at a height of three feet above the ground. Many farmers report the successful protection of crops, such as alfalfa and even fruit, by irrigating during the night of the frost.

4. Frost usually occurs on clear nights because of the absence of a cloud blanket, which blanket prevents the upward escape of heat. Smudges are to supply an artificial cloud or blanket of gas or smoke which is not transparent but rather absorbs well the heat and prevents its upward escape. Carbon dioxide, water vapor, and unburned carbon (which are the products of ordinary combustion), ammonia, gaseous hydrocarbons, dust, and smoke are the best materials for smudge because their diathermancy is small.

5. Ninety-six pounds of carbon dioxide were liberated during the night on an acre in an hour and one-half. The treated area cooled just as fast as the adjoining untreated area.

6. An area of ten by fifty feet surrounded by brick walls with no roof was supplied with carbon dioxide as fast as it would run out of a tank, the neck of which was kept warm with hot

cloths. This was done when the temperature of the surrounding area was cooling and it was found that the treated area cooled at the same rate as the untreated area.

7. Electric heaters were placed in the bottom of an approximately air-tight box, two and one-half feet by four and one-half feet and seven and one-third feet deep, and they gave a rise in temperature of 14.1° F. With 22 pounds of carbon dioxide (three times the volume of the box) which had been warmed to the same temperature as the box before it entered, the heaters gave a rise of 2.8° F. more than with no smudge, the gas being liberated in 15 minutes. A test of the air inside of the box showed three per cent carbon dioxide there. This result was duplicated on a larger scale by heating (with electric heaters) an area 500 square feet surrounded by walls.

8. During April the upper two or three inches of the ground is only slightly warmer than the air. This condition lasts only a few hours during the night, so that the rate of transfer of heat upward is slow and spring frosts usually occur several nights in succession with the intervening days comparatively cool; hence, smudging would be quite ineffective on the second and third night, and we think smudging is entirely unsatisfactory unless heat be supplied with it.

9. Tests to see the effect of spraying warm water over the tree which would liberate heat on cooling and on freezing and should help retain heat of the earth by acting as a smudge did not prove that the practice was satisfactory. The sediment in the water, clogged the really fine spray and the coarse spray even though the water was warm before leaving it, collected in the fruit buds and froze them, producing the same effect as a storm of sleet.

10. One hundred horse-power of electrical energy when converted into heat in the open air gave a temperature rise of 20° F., the temperature outside being 70° F. It required approximately 14 watts per square foot to obtain 1° F. rise in temperature.

11. On clear, quiet, frosty nights the out-doors can be heated with pots because the heated air only rises 50 to 75 feet, due to the temperature inversion layer.

12. A table containing results of 15 investigations of other stations shows that with 100 heaters to an acre the orchard will remain about 4° F. warmer than the surrounding unheated area. Winds of ten miles an hour reduce this to less than one

and one-half degrees F.

13. Figuring that it would be necessary to heat twelve nights in ten years, we have compared the cost of heating with the oil and coal. With oil costing 9 cts. a gallon and coal selling at $7 a ton, it would cost $21 a year an acre to heat with oil and $17 with coal. With coal at $7 a ton, oil must be purchased at 7c a gallon to compete with it, but labor costs are less with oil. The smudge from the two fuels is about equally valuable.

14. The equipment necessary, and the best method of orchard heating, the forecasting of frost, and the cooperation of the Weather Bureau, are given with considerable detail.

15. Tables are given showing the results of our experiments on hardiness of fruit buds to frost. It is a fact that most people start their fires too soon and too often because they think buds more sensitive to cold than they really are.

16. Tables are given showing average dates of the blooming periods of apples and peaches in the five leading horticultural counties of Utah. Data are given to show the number of nights each year that heating would have been necessary in the past 16 years.

17. A careful study of the data on fruit yields, selling price, and frost damage shows that by the most economical heating the value of the fruit saved is approximately equal to the cost of saving it—assuming the heating will always save the crop no matter how much or how severe the frost. There is also to be considered the worry of watching for the frost, although in Utah in nine cases out of ten the crops can be saved, yet financially it does not pay when peaches sell at 55c or less and apples at 75c a bushel or less.

18. Mathematical equations are worked out, graphed, and explained in words that express the following facts:

Considering a farm as an investment, when the general cost of producing the fruit and the interest on the investment are subtracted from the money received from the sale of the fruit, there is usually expected a small profit. (Many farmers considering their place as a home that provides employment for the family expect only a small interest, saying nothing about a profit.) If in the production of the above yield orchard heating was resorted to in order to save it from killing frost, then this heating cost should be added to the general cost of production in calculating the profit. For the business to be profitable, the receipts from the sale of the fruit should be high and the general cost of production, including the investment and the cost of heating (cheap fuel, etc.), low.

19. Everything else being the same, except that one of two localities experiences frost, of course the frost-free one is the better, but where both experience frost heating may or may not increase the cost of production, depending entirely on whether the fruit saved by the heating brought in more money on sale than it cost to save it by heating. A place where frost occurs can compete with a frost-free locality if the general cost of production and the interest (because of cheaper land) is sufficiently lower to more than offset the cost of heating.

20. Tables are inserted giving the sale price that must be obtained for the fruit in order to obtain different rates of interest on land of various values with and without heating for various cost of production. These selling prices are high and in most cases higher than the farmers receive, but they are many of them expecting and getting only employment for their families.

21. A farmer will increase his profits or decrease his losses by heating if the value of the crop before it is picked is more than the complete cost of the heating. Whether the yield is large, small, or nothing, the place must be cared for almost exactly the same, and the cost of heating must include, not only the oil and labor while the heating is being done, but must include the interest and depreciation of the heating equipment.

22. The more times that killing frosts occur the more expense would be incurred in protecting against them, but the more fruit would be saved, and where frost occurs frequently enough to be at all serious, the number of nights that heating must be resorted to is almost proportional to the amount of fruit that is saved, so that whether it pays or not to heat an orchard is not a function of the frequency of the frosts. Whether one should heat or not is not a function of the amount of money invested in the place unless the heating is to protect the trees. Of course, in determining the profits the land value certainly enters. To increase one's profits or decrease his losses by heating, the sale price of the fruit must be high, the fuel must be cheap, the frosts must not be accompanied by winds, and the heating must be carried out according to the most modern methods with military precision.

It is very doubtful whether it pays in Utah.

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Utah Agricultural College

EXPERIMENT STATION

Bulletin No. 139

The Movement of Soluble Salts with the Soil Moisture

By

F. S. HARRIS

Logan, Utah, May, 1915

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THE MOVEMENT OF SOLUBLE SALTS WITH THE SOIL MOISTURE.

By

F. S. HARRIS

1. Introduction.

In irrigated districts, where excessive quantities of water are used, there is usually an accumulation of alkali salts in the soils of the lower lands. These salts are probably dissolved from the soils through which the percolating waters pass and are carried along until the water comes to the surface and is evaporated, when the salts are deposited as a crust at the surface. Many of the most fertile soils of the arid regions have been ruined by the bringing to the surface of soluble salts in such large quantities that the growth of crops is prohibited. The rapidity with which salts can be removed by water is also an important question in the reclamation of alkali soils by drainage.

In order to determine more exactly the movement of salts with water through the soil, a number of experiments were made using small sections of soil containing various quantities of soluble salts. Water was passed through these soils horizontally and vertically and the salts later determined in different parts of the soil. While these sections of soil do not exactly duplicate field conditions, they probably, on a small scale, obey the laws which operate when water passes through field soils.

2. Horizontal Movement of Salts.

Special tanks were arranged to study the horizontal movement of salts through the soil. These were made of galvanized iron and were six feet long, one foot wide and four inches deep. Soil was placed in the tanks to a depth of three inches and the entire surface sealed over with paraffined paper, except a square foot at one end which was left uncovered. This made five square feet of the soil covered, and one square foot open for the free evaporation of water.

On the end of the tank opposite the uncovered portion, was an opening into the tank through which water was poured. The water entering this opening passed horizontally through the soil to the other end, there being evaporated from the square foot of uncovered soil surface. Water was added from time to time so that there was always a movement toward the evaporating end.

TABLE 1.—SOLUBLE SALTS IN EACH SECTION OF SOIL THROUGH WHICH TEN LITERS OF WATER HAD PASSED HORIZONTALLY.

Parts Per Million of the Dry Soil.

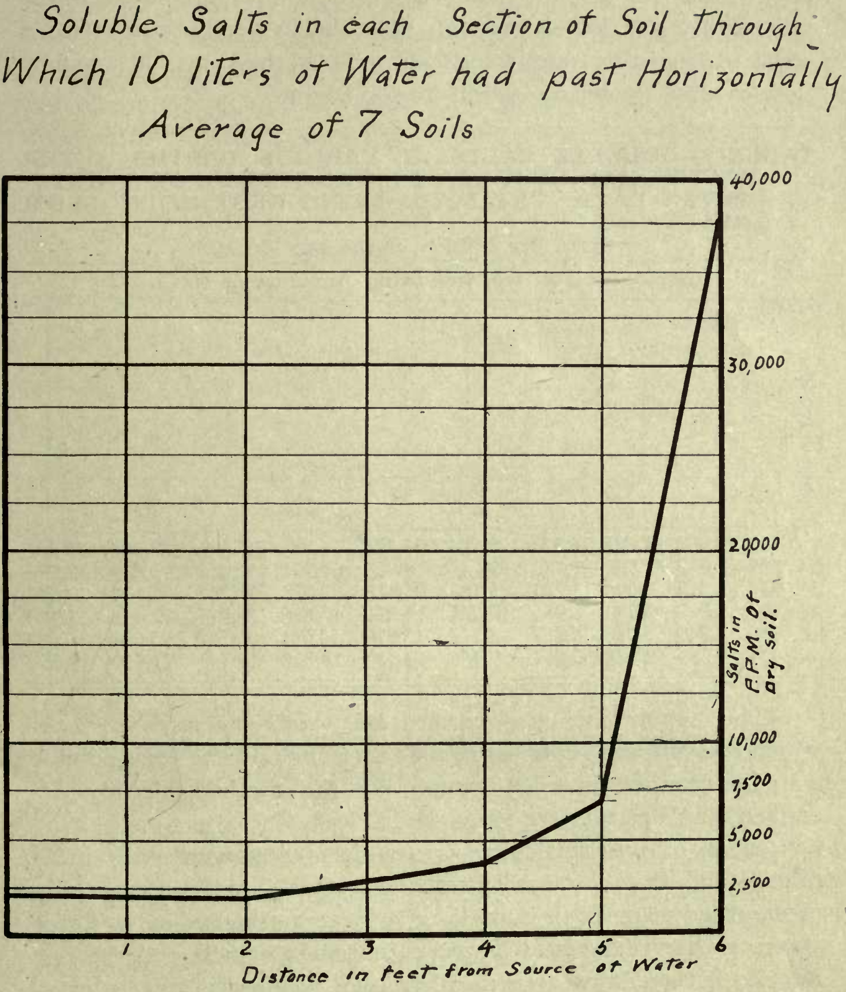
No. of Section from Source of Water	Greenville Loam	Greenville Loam plus 1% NaCl	Greenville Loam plus 2% NaCl	Sand	Clay	Muck	Manure	Average
1	1,269	130	8,076	808	544	1,004	2,072	1,986
2	742	2,048	5,160	146	540	1,185	2,632	1,782
3	1,129	6,043	5,307	127	536	1,809	4,460	2,773
4	542	4,406	9,318	94	642	1,893	8,123	3,574
5	724	24,345	14,245	291	2,326	2,563	5,279	7,110
6	3,750	83,320	123,094	312	4,126	4,018	60,189	39,830

The experiment was begun August 23, 1912, and continued till February 10, 1913. During this period 10 liters of tap water passed through the soil in each tank. There were seven tanks in all, each containing a different soil treatment.

At the end of the experiment the soil was removed from the tanks in foot sections, and the samples numbered; number one being given to the section where the water was added, and number six to the section where the evaporation occurred.

The total soluble salts were determined by adding 500 c. c. of distilled water to 100 grams of soil, stirring for three minutes, then letting settle twenty minutes, and filtering through a Chamberlain-Pasteur porcelain filter; 50 c. c. of the filtrate was evaporated to dryness and the weight of the residue determined. The results are given in Table 1 and Figure 1.

It will be noted that the salts moved with the current of water and accumulated at the end where evaporation took place from the surface. In general, the salts increased in the soil from the end where the water was added to the other end. The increase was not in every case regular. The figures bring out clearly the fact that the soluble salts in the soil move horizontally with the current of soil moisture.



Soluble Salts in each Section of Soil Through Which 10 liters of Water had past Horizontally
Average of 7 Soils

3. Upward Movement of Salts.

Evaporating cans of the Stevenson and Schaub model, eleven inches in diameter and thirteen inches deep with a water supply tube at the bottom, had ten kilograms of Greenville Loam containing different amounts of sodium chloride placed in them. There were nine treatments in all with the following amounts of NaCl on the basis of the dry soil: (1) none, (2) .5 per cent, (3) 1 per cent, (4) 2 per cent, (5) 3 per cent, (6) 4 per cent, (7) 5 per cent, (8) 6 per cent, (9) 7 per cent. The soil was all made up to the same percentage moisture, and water added through the tube in the bottom twice a week to keep the weight constant. Thus, there was a constant flow of water from the bottom to the surface.

TABLE 2.—SOLUBLE SALTS IN VARIOUS DEPTHS AFTER WATER HAD EVAPORATED FROM SOIL FOR THIRTY-SEVEN DAYS. THE SOILS BEING KEPT MOIST FROM BELOW.

Parts Per Million of the Dry Soil.

Greenville Soil and Following Amounts of NaCl.

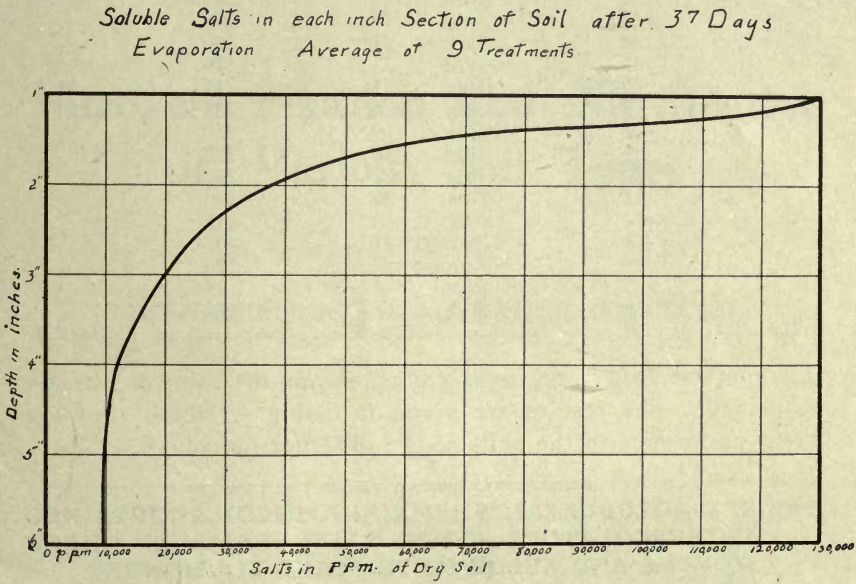
Depth in inches	None	.5 %	1 %	2 %	3 %	4 %	5 %	6 %	7 %	Average
1	1,730	17,408	30,082	75,223	100,241	233,875	216,886	217,045	273,794	129,587
2	716	6,479	12,892	21,332	27,744	8,623	61,921	102,452	95,829	37,554
3	727	3,310	6,594	12,224	15,782	24,816	29,070	37,143	56,179	20,649
4	492	1,792	3,270	7,956	10,277	14,321	17,678	23,925	27,482	11,910
5	388	1,249	3,056	4,327	8,107	13,690	14,601	19,518	25,089	10,003
6	424	1,751	2,521	5,114	7,426	12,920	14,708	19,591	21,510	9,552

The experiment was carried on thirty-seven days, after which the soil was removed in inch sections and the total soluble salts determined in each sample by the method already described. The results are given in Table 2.

In all of the cans there was a decided upward movement of salts and an accumulation at the surface. This was especially pronounced in the soils containing a large amount of salt. There was a greater difference between the surface inch and the one next to it than between any other two. This was due to crystallization of salt at the surface. The experiment shows that salts move readily upward with the water current and illustrate the method of alkali accumulation on the surface of irrigated lands.

4. Leaching of Soils.

Five glass percolators of the Oldberg type were filled with Greenville loam and arranged on a rack, one above another in such a way that water dripping from the top one percolated into the one below and so on to the bottom. Above the top percolator was an inverted water bottle which was kept filled with water. This maintained a constant level of water above the soil in the top percolator. A bottle was kept below the bottom percolator to catch all the water that passed through it. When one bottle was filled with the drainage water another was put in its place.



The experiment was begun June 11th and allowed to run till September 11th, a constant stream of water percolating through the soils during the entire time. In all, about fifty liters of water passed through the soil. This was caught in sixteen bottles which held about three liters each. The soluble salts were determined in each bottle separately. The results are given in Table 3.

The first leaching contained 651 parts per million of solids. After this the salts dropped down to about 200 p. p. m. and remained fairly constant during the remainder of the experiment. The variations that occurred may have been due to differences in temperature or other factors during the experiment.

The soil was allowed to remain in the percolators six months after the leaching had been discontinued. The nitrates and soluble salts were then determined in the soil of each percolator.

TABLE 3.—SOLUBLE SALTS IN SUCCESSIVE LEACHINGS OF 3 LITERS EACH FROM PERCOLATORS.

Number of Leaching	Dates	Solids in Parts per Million
1	June 11-13	651
2	June 15	221
3	June 18	188
4	June 21	190
5	June 27	179
6	July 1	215
7	July 6	233
8	July 9	250
9	July 16	222
10	July 22	217
11	July 26	199
12	August 10	217
13	August 21	198
14	August 27	194
15	Sept. 3	193
16	Sept. 11	172

The method used in extracting the soil was the same as already explained. The results are given in Table 4, which shows a great uniformity in the soils of the different percolators.

TABLE 4—SOLUBLE SALTS REMAINING IN SOILS CONTAINED IN PERCOLATORS AFTER BEING LEACHED THREE MONTHS AND ALLOWED TO STAND SIX MONTHS.

No. of Percolator From Top	Total Soluble Salts in p. p. m.	Nitrates in p. p. m. Nitric Nitrogen
1	599	106
2	532	123
3	532	125
4	552	103
5	512	107

5. Conclusions.

1. The accumulation of alkali salts in soils which were previously fertile has necessitated the abandonment of a great deal of land in the irrigated portion of arid America.

2. Experiments reported in this publication show that salts are transferred through the soil very readily by moving water.

3. It is probable that low lands will continue to be ruined by the accumulation of alkali salts as long as the uplands are over irrigated.

APRIL, 1915 TECHNICAL BULLETIN 3

VIRGINIA POLYTECHNIC INSTITUTE

VIRGINIA AGRICULTURAL EXPERIMENT STATION

Nitrogen Fixation and Nitrification in Various Soil Types

BY

HOWARD S. REED and BRUCE WILLIAMS

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FOUR PAPERS ON

NITROGEN FIXATION AND NITRIFICATION IN VARIOUS SOIL TYPES.

By HOWARD S. REED AND BRUCE WILLIAMS.

(1)—The Effect of Mineral Fertilizers on Nitrogen Fixation and Nitrification in the Soil.[1]

The bacterial flora of soils which have received prolonged and definite applications of mineral fertilizers has been the subject of rather meager attention. The status of bacterial activities as regard inorganic substances is imperfectly understood and, while a subject of considerable interest, it is justifiably relegated to a secondary place in soil bacteriology investigations. Yet to note the bacterial activities of any soil which has received "control" treatment is eminently worth while since some condition may be observed which exerts an unmistakable influence. This paper reports a study of nitrification and nitrogen fixation on soils that had received annual applications of fertilizers for five years.

Through the courtesy of Prof. T. C. Johnson an opportunity was afforded in 1913 to study the soils of some of the experiment plats of the Virginia Truck Experiment Station. The soil samples were taken from twentieth acre plats which had grown various truck crops, none, however, which should have exerted a peculiar influence on the bacterial flora. The samples were carefully taken and immediately brought to the laboratory. The fixation tests were made by incubating ten grams of soil in 100 c. c. Ashby's solution for 21 days and making total nitrogen determinations for the increase. For nitrification tests, 400 grams of soil in Erlenmeyer flasks was incubated with 1 percent ammonium sulphate for six weeks, at the end of which period nitrate determinations were made by the Iron-Zinc Reduction method.

Tables I and II give the results of these tests. Under the column " Annual Fertilizer Treatment " is given the amount of fertilizer the soils received annually per acre for five years. The laboratory numbers are the same for both tables.

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[1] Paper 36 from the Laboratories of Plant Patholoigy and Bacteriology, Virginia Agr. Exp. Sta.

TABLE I.—*Nitrogen Fixation Tests.*

Lab. No. Soil Sample	Annual Fertilizer Treatment	Mgs. of N. per 100 c. c. Ashby's Solution with 10 grams soil		
		At Beginning	After 21 Days	Ave. Increase
1	Control; no fertilizer	8.1 9.3	18.48 18.94	10.01
2	Crimson clover turned under	11.2 10.9	19.88 18.34	8.6
3	Crimson clover turned under 1500 pounds Hydrated Lime	8.26	21.21	10.6
4	15 T. stable manure Acid (Rock) phosphate, (16 percent available phosphoric acid), 2000 pounds 1 year; 1000 pounds 4 years	8.6	21.84 22.12	13.48
5	Same as 4 with 1500 pounds Hydrated Lime additional	7.28	22.76	15.48
6	Acid (Rock) phosphate, (16 percent available phosphoric acid), 2000 pounds 1 year; 4000 pounds 4 years	7.7 8.5	17.74	9.62
7	Kainit, (12 percent actual potash), 1000 pounds	8.5 9.1	21.56	10.7
8	Cotton Seed Meal, (7 percent nitrogen, 2 percent phosphoric acid 2 percent potash), 4000 pounds	8.4 8.6	21.3	10.8
9	Peruvian Guano, (4 percent nitrogen, 2 percent phosphoric acid, 4 percent potash), 2000 pounds	7. 7.5	17.31	10.6
10	Nitrogen, (4 percent NaNO$_3$) Potash, (8 percent KCIC), 1000 pounds	6. 6.5	20.16	13.9
11	Phosphoric Acid, (8 percent), KCIC (8 percent); 1000 pounds	6.3	15.47	9.17

TABLE II.—*Nitrification Tests.*

Lab. No.	Mgs. of N. Nitrogen per 100 gms. dry soil	
	At beginning	After six weeks
1	.9	4.42
2	1.74	8.12
3	....	27.7
4	....	9.74
5	....	22.52
6	....	6.44
7	....	7.01
8	2.2	4.73
9	2.0	6.96
10	....	2.28
11	....	2.74

Reviewing Table I, we note the failure of the various inorganic fertilizers to offer any marked stimulation to nitrogen fixation. The soils all have a rather high nitrogen fixing power, yet the control plat which received no fertilizer has an Azotobacter flora which is excelled in only one or two cases. The maximum fixations are attained under the influence of stable manure, and that with lime records the highest increase in nitrogen noted in the series. The minimum fixation, that from soil No. 2 which had crimson clover turned under without lime, is not unexpected. The acid condition resulting from such a practice would undoubtedly account for this decrease. The high fixing power of soil No. 10 is difficult to explain. It does not appear probable that nitrate of soda should induce any special development of Azotobacter. If so, it is significant that less nitrogen in this form was more conducive to their growth than were larger quantities of organic nitrogen. The action here suggests a parallel to the benefit which leguminous crops are supposed to derive from light dressings of nitrate of soda during the early stages of growth.

The Azotobacter films on all of the soils were uniformly good and those on soils Nos. 3, 4, and 5, were the richest ever observed in this laboratory.

The nitrification tests are assertive in at least one point, namely, the conspicuous results obtained by the use of lime. From Table II it will be seen that crimson clover increased the nitrifying power of the soil 83 percent while crimson clover and lime produced an increase of 526 percent. The use of stable manure likewise increased nitrification 120 percent and the addition of lime here produced a 407 percent increase. The combination of crimson clover and lime was more efficient in promoting nitrification than was stable manure and lime. The remaining soils except Nos. 10 and 11 gave uniformly higher nitrifying power than the control plat, yet it is questionable that any combination of fertilizers was responsible for this. Their use probably induced general fertility, which stimulated nitrification somewhat, yet no striking result is noted—certainly none commensurate with that produced by lime, for example.

(2)—Studies on Nitrogen Fixation in Various Soil Types[1]

The process of nitrogen fixation of Azotobacter has been definitely established; it is probably of widespread activity; its importance is of disputed magnitude, regarded as paramount in soil fertility by a sanguine few, but held in abeyance by a significant number of others. Despite the investigation which the problem has received, no very definite conclusions can be drawn. The unexpected fixation by one soil, the near failure of another, possessing the qualities usually ascribed to soils of high fixation power, are obstacles to the investigator who would dogmatically assert the conditions upon which fixation depends. Depreciate as one may the importance of Azotobacter as a significant source of nitrogen, the striking quantity of that element in virgin soils, its accumulation in fallow lands, its partial maintenance in cultivated fields can be accounted for by no more plausible theory than by attributing it to the activities of the above mentioned organism—to this or to anaerobic bacteria possessing similar faculties for fixation.

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[1] Paper 37 from the Laboratories of Plant Pathology and Bacteriology, Virginia Agr. Exp. Sta.

The present paper deals principally with comparative fixation in virgin and cultivated soils of the same type, and with the process as affected by soils of widely different texture. It notes also the quantities of nitrogen in virgin and cultivated soils that have been collected from various sections of the State and the relationship, if any exists, between the original nitrogen content and the increase by fixation.[1]

Virginia is a State of wide variety in its soil types. It presents many gradations from the heavy red clay of the Piedmont section to the fine sandy loam of Tidewater Virginia. The Bureau of Soils of the U. S. Department of Agriculture has surveyed twelve widely different sections of the State and classified the soil types therein. It was on the basis of this classification that the soils used in the present work were collected. A few were obtained outside of the surveyed area yet these were characteristic in their texture. Many soils of the same name and type but from widely separated areas were collected that various sections as well as soil types might be represented. In practically every case two samples of each type were collected, one uncultivated and the other under cultivation at the present time. The term "virgin" might be properly applied to the uncultivated series, for in the majority of cases they have never received cultivation and all have lain idle for a number of years.

An agent from the station in many cases did the collecting, and, when this was not the case, instructions were sent to the various county demonstrators, who kindly coöperated in the work. About two gallons of soil were obtained for each sample and shipped to the station by express. As soon as they arrived, the soils were screened and placed in covered tin pails especially constructed for the purpose, and from these composite samples were obtained for the various tests. Soils number 1-55 were collected between May 13 and November 25, 1913, and those from 56-93 were collected between April 10 and July 26, 1914. In every case the tests were made immediately after the soils were brought to the laboratory.

FIXATION TESTS.

The fixation tests were carried on in solution. Whether or not this method is representative of field conditions, it is the only satisfactory one we have found for measuring fixation. Some preliminary tests were made at the beginning of the work, using plates with 400 grams of soil to which were added 4 grams of mannite and kept at 28° C. for 21 days. But the fixation by this method was so slight that it gave no index to the comparative power of the soils to fix nitrogen. The method finally used employed 100 c. c. of Ashby's solution in 1 litre Erlenmeyer flasks to which were added 10 grams of soil. The Ashby's solution was made according to the following formula:

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[1] This work was planned and started by Dr. E. B. Fred, formerly bacteriologist in this Experiment Station, before his removal to the University of Wisconsin. The authors wish also to acknowledge their indebtedness to Professor R. J. Holden for suggestions regarding the geology of soil types in this State.

Mannite	20	grams
NaCl	.2	"
Mg SO_4	.2	"
Ca SO_4	.1	"
K H_2PO_4	.2	"
Water	1000	c. c.

The mono-potassium phosphate was dissolved separately and neutralized with NaOH.

Four 10 gram portions from each soil were weighed out on a dry basis. Two of the Erlenmeyer flasks, containing 100 c. c. of solution, each received 10 grams and the remaining portions were analyzed for total nitrogen by the Kjeldahl method. The flasks were incubated for 21 days at approximately 28° C. at the end of which time their entire content was analyzed for total nitrogen by the method previously employed. The average from the two analyses was taken. There was always close agreement in the two results from the soil itself and seldom any wide variations in the fixation flasks. Where this did occur, the tests were repeated. The slight variations which always accompany fixation tests are impossible to avoid. In Table I is given the soil type as classified by the Bureau of Soils, the original nitrogen content of the virgin and cultivated soils, and the increase in each after 21 days incubation of 10 grams in 100 c. c. of Ashby's solution. The first of the two numbers refers to the virgin soil.

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TABLE I.—*The Fixation of Nitrogen by Various Soil Types in Ashby's Medium.*

No. Soil Sample	Soil Type	Mgs. N. Originally present per 10 gms. soil		Increase in mgs. per 10 gms. soil after 21 days with 100 c. c. Media			
		Virgin	Cultivated	Virgin	Cultivated	Virgin Per ct. Increase	Cultivated Per ct. Increase
1-2	Hagerstown Silt Loam	13.8	12.6	2.95	3.5	14	28
3	‘‘ ‘‘ (Rich)	13.8	14.35	2.95	4.55	14	31
4-5	‘‘ Stony ‘‘	9.31	20.86	2.38	10.76	25	52
6	Hudson River Shale (Meadow)	....	27.4	....	3.5	..	12
7-8	DeKalb Silt Loam	14	20.72	1.82	3.22	13	11
9-10	‘‘ Stony ‘‘	15.26	10.11	3.22	8.47	21	84
11-12	‘‘ Silt ‘‘	17.5	16.1	3.68	4.6	21	28
13-14	Hagerstown Silt Loam	15.82	21.97	12.18	14.08	76	64
15-16	‘‘ ‘‘ ‘‘	10.7	16.3	8.2	14.4	76	88
17-18	‘‘ ‘‘ ‘‘	12.3	8.6	10.16	16.7	82	193
19-20	Cacapon Sandstone	21.4	21	6.39	5	29	23
21-22	Devonian Shale	11.4	14.28	13.6	16.7	118	110
23	‘‘ ‘‘ (Flood Plain)	14.7	....	4.7	....	32	..
24-25	Clay Loam	28	15.58	10.7	14.84	38	95
26-27	Sandy Loam	3.7	4.9	7.1	13.22	190	270
28-29	Cecil Clay	8	7.8	14.9	5.1	186	65
30-31	Clay Loam	9.6	8.3	13.39	12.5	140	150
32-33	Iredell Clay	16.8	10.6	4.58	2.18	27	20
34-35	Cecil Loam	13.28	9.38	6.36	8.17	47	86
36	‘‘ ‘‘ (Meadow)	....	10.05	....	15.15	..	140
37-38	Loudon Sandy Loam	10.49	6	5.51	7.34	52	90
39-40	Cecil Clay	11.6	8.1	5.19	3.84	44	47
41-42	‘‘ Loam	9.6	13.7	12.31	17.3	128	125
43-44	‘‘ Sandy Loam	7.6	3.9	5.23	18.8	68	480
45-46	Iredell Clay Loam	11.6	7.9	2.3	3.6	18	45
47-48	Sandy Loam	6.4	4.62	5.77	4.53	90	98
49-50	Clay Loam	5.5	7	3.65	4.76	66	66
51-52	Norfolk Sandy Loam	6.5	1.3	11.45	8.6	175	661
53-54	Leonardtown Loam	6.4	6.4	6.37	7.43	99	113
55	Swamp	16	....	12.8	....	79	..
56-57	Black Clay	21.26	25.48	12.46	10.34	58	40
58-59	Norfolk Sandy Loam	9.52	4.18	2.21	8.8	23	210
60-61	Leonardtown Loam	8.8	6.7	3.56	15.48	40	229
62-63	Sandy Loam	4.8	5.4	11.3	10.6	235	196
64-65	Cecil Clay	6.7	5.5	14.31	10.27	213	194
66-67	‘‘ Sand	9.78	3.8	6.7	16.45	67	432
68-69	Iredell Clay	8.82	7.56	6.98	6.35	78	84
70-71	Cecil Clay	19.04	5.57	8.8	7.1	46	127
72-73	Fine Sandy Loam	6.72	4.62	7.11	8.1	105	175
74-75	Cecil Sand	3.25	3.6	5.41	5.32	166	148
76-77	Hagerstown Loam	10.5	11.9	6.3	7.84	60	65
78-79	Clay Loam	13.5	12.6	8.72	8.6	64	68
80-81	Cecil Clay	9.6	10.5	7.9	5.49	82	52
82-83	Hagerstown Clay	8.6	9.5	5.6	4.9	65	51
84-85	‘‘ Loam	25.8	16.1	8.6	5.3	33	32
86-87	‘‘ Sandy Loam	12.3	9.5	7.84	5.69	63	59
88-89	‘‘ ‘‘ ‘‘	11.3	9.6	4.29	5.82	37	60
90-91	Edgewater Stony Loam	8.8	5.6	5.18	5.4	58	98
92-93	Sandy Loam	3.6	5.7	7.2	7.7	200	135

By referring to Table I it will be seen that there were 93 soils examined and of these 88 were in pairs, that is, consisting of a virgin and cultivated sample. From these 44 pairs, 26 gave a higher fixation by the cultivated and in 18 the virgin soil excelled in the addition of nitrogen. The average increase where the cultivated soils were highest was 3.98 mgs. and where the virgin samples excelled the average gain was 2.08 mgs. The total nitrogen fixed by the virgin samples was 331.66 mgs., and that fixed by the cultivated samples was 389.74 mgs., or a total increase of 58 mgs. Table II summarizes these several points:

TABLE II.—*Giving the Comparative Results of Nitrogen Fixation by 44 Virgin and 44 Cultivated Soils.*

Number of Pairs in which Cultivated Soils excelled	26	
Number of Pairs in which Virgin Soils excelled	18	
Average Increase where Cultivated Soil excelled	3.98	mgs.
Average Increase where Virgin Soil excelled	2.08	"
Total Nitrogen fixed by Cultivated Soils	389.74	"
Total Nitrogen fixed by Virgin Soils	331.66	"
Original Nitrogen in Cultivated Soils	455.25	"
Original Nitrogen in Virgin Soils	513.38	"

The superiority of cultivated soils in fixing nitrogen is strongly indicated by results from the foregoing table. They are in accord with the recent findings of Greaves[1] though not so pronounced, due perhaps to very dissimilar conditions. A substantial majority of the soils examined showed a higher fixing power by the cultivated samples than by the virgin, and the increase where noted in cultivated soils was relatively much higher than when it took place in the virgin soils. These results are without regard to any factor save that of cultivation and for this reason are all the more significant. They represent tests from a large number of soils of varying texture, collected from definitely separated areas, and the cultivated samples had experienced a variety of types of cultivation. Notwithstanding these facts the evidence which points to the advantages of cultivation in developing the Azotobacter flora is unmistakable. This would seem at least one indubitable stimulation which free nitrogen fixation may receive.

An interesting point is the higher original nitrogen content of the virgin soils as compared with the cultivated ones. The analyses of 44 virgin samples showed that in 29 of that number there was more total nitrogen than in the corresponding cultivated samples, and of the 18 virgin samples which excelled the corresponding cultivated ones in fixation, 15 had also more total nitrogen. Yet it is difficult to trace from the foregoing results any relationship between the amount of nitrogen in a soil and that which it adds by fixation. It is probable that under field conditions, as Koch and Seydel[1] have shown, the removal of nitrogen by crops is necessary to further fixation. The results obtained from the above tests do not indicate that the presence of nitrogen is of material influence on fixation.

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[1] Greaves, J. E. A study of bacterial activities in virgin and cultivated soils. Cent. f. Bakt. II. Abt. Bd. 41., p. 444.

As previously stated an effort was made to observe the influence of soil texture on fixation. It would be interesting to note the intensity of the development of the Azotobacter flora in soils of widely different types and to investigate the marked differences where they do appear. The widespread occurrence of Azotobacter is not suggestive of its susceptibility to difference in soil types. Von Feilizen, however, has reported the very slight occurrence of Azotobacter in peat[2] and moor[3] soils, even after long periods of cultivation, and, though probably without much justification, the idea has grown up that fixation is more marked in soils of light open texture than in the heavier soils. Since cultivation obviously affects the process and the cultivated soils considered in this paper received cultivation varying widely in kind and intensity, it would be illogical to compare results from them as evidence in support of fixation by any special type. It is only, therefore, the virgin samples which are considered in this relationship. A general classification of five different types was found to include all of the 44 virgin samples, and, while the number of soils was not the same in every classification, an average of the nitrogen fixed by each class would reveal any noteworthy difference between them. In Table III is given the soils with their numbers which were thus classified and the average in milligrams of nitrogen which each type fixed.

Table III.—*Average Nitrogen Fixed by a Number of Virgin Soils of Various Texture.*

Soil sample numbers	Classification	Average in Milligrams of Nitrogen fixed
51, 53, 58, 60, 66, 72, 74 (7)	Fine Sandy Loam	6.11
19, 26, 47, 62, 86, 88, 92 (7)	Sandy Loam	7.12
1, 3, 4, 7, 9, 11, 13, 15, 17, 34, 37, 41, 43, 76, 84, 90 (16)	Loam	5.7
24, 30, 45, 49, 78 (5)	Clay Loam	7.75
21, 23, 28, 32, 39, 56, 64, 68, 70, 80, 82 (11)	Clay	8.99

The comparison would perhaps be more fair if the number of soils in each type were the same, but since the average is taken it seems justifiable to report on all the soils. Collected as the soils were with reference only to soil type and having received no treatment whatever, the results have a considerable degree of interest. The nitrogen fixing flora has presumably been influenced by no factors other than the natural inorganic status of the soil, its humus content, and its physical condition. To be sure, the two first named factors may be of controlling importance—we are inclined to believe the supply of humus is an all important one in comparison with which the others are relatively insignificant. The only difference in the above figures which would warrant conclusions is that between the clay soils and those of lighter texture. And that fixation in these heavy soils should exceed that of the lighter ones is not without its element of surprise, yet the difference is quite well defined—even the clay loam exceeds the loams and the sandy loams in fixing nitrogen.

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[1] Koch and Seydel. Cent. f. Bakt. Abt. II, Bd. 31. 1911. p. 570.
[2] Feilitzen von H., Svenska Mosskulturfor. Tdskr. 25, 1911, No. 1, pp. 53-57.
[3] Feilitzen von H., Fuhling's Landw. Ztg. 59. 1910. No. 14, pp. 489-492.

Rather than asserting the superiority of clay soils or of any special soil type in fixing nitrogen, the results summarized in Table III more poignantly demonstrate the indifference with which that process is affected by such factors. This fact has been impressively presented in many instances in the present study.

By singling out from Table I the results from a few cultivated soils regardless of their origin and noting their power of fixation, it is difficult to ascribe any influence whatever to soil types. Such examples are presented in Table IV.

TABLE IV.—*Nitrogen Fixation by a Number of Cultivated Soils of Various Types.*

No.	Soil Types	Milligrams Nitrogen fixed per 100 c. c. Media with 10 gms. soil
52	Norfolk Fine Sandy Loam	8.6
27	Sandy Loam	13.22
85	Hagerstown Loam	8.6
31	Clay Loam	12.5
65	Cecil Clay	10.27
55	Swamp	12.8

Under proper cultivation and a sufficient supply of humus—disregarding for the moment certain other factors—it appears that the type of a soil would have negligible influence on its power for free nitrogen fixation.

SUMMARIZING DISCUSSION.

The examination of ninety-three soils, eighty-eight of which were collected in pairs of virgin and cultivated samples, showed clearly the superiority of cultivated soils for nitrogen fixation. Though some of the virgin samples excelled in the addition of nitrogen, the average increase, where induced by cultivated soils, was appreciably higher than where it resulted from virgin soils. Tables I and II summarize these results.

Fixation by the virgin samples was noted also with regard to soil type, since a number of samples of widely different character were examined. The results from a number of virgin soils of the same type were averaged and compared with averages from other soil types. The average from the clay soils was highest, showing quite a perceptible increase over the lighter soils. But on account of results in fixation tests with cultivated soils, the writers hesitate to ascribe any marked influence to soil texture and regard it as a rather immaterial factor. Many cultivated soils, regardless of type, showed notable nitrogen fixing power. In Tables II and IV are to be seen summaries of these points.

In connection with results obtained in the present work, the reports of previous investigators along this line are of interest. A reference to the work of Greaves, in which he found higher nitrogen fixing power of virgin than of cultivated soils, has been previously made in this article. A notable amount of work on factors which influence fixation has concerned itself with the alkalinity[1] and phosphate[2] content of soils. The concensus of these reports emphasize the importance of lime in fixation. That phosphates are essential to the proper development of Azotobacter has been amply demonstrated by laboratory tests, but it is questionable whether they are ever a limiting factor under field conditions. Some fixation tests at this station on soils which had received various combinations of mineral fertilizer for five years fail to disclose any results that might be attributed to inorganic causes.

The general indications from fixation studies which the authors have carried on are that—with the possible exception of lime—the humus content of a soil and its cultivation are the only factors which materially affect fixation. It would seem that with these properly adjusted the process could always reach its maximum efficiency—cultivation to promote æration and removal of nitrogen, and humus to supply the energy essential to the activities of the nitrogen fixing flora.

(3)—Studies on Nitrification in Various Soil Types.[3]

The accumulation of so great a number and variety of soils afforded an unusual opportunity for observing the process of nitrification. To study it contemporaneously with fixation was of no little interest for it is probable that each is affected by many of the same factors.

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[1] Ashby, S. F. Jour. Agr. Sci. 2. 1907. No. 1, pp. 31-51.
Christensen, H. R. Cent. f. Bakt. II Abt. 17, 1906, Nos. 3, 4., pp. 109-119. Figs. 2, 5, 7, pp. 161-165; Figs. 2, 11-13. pp. 378-383.
Fisher, H. Journal f. Landw, Bd. 53, 1905. p. 290.
Gerlach und Vogel. Cent. f. Bakt. Abt. II. Bd. 9, 1902. p. 891.
Hoffman and Hammer. Cent. f. Bakt. Abt. II, Bd. 28, 1910., pp. 127-139.
Lipman, J. G. Ann. Rept., N. J. Exp. Sta. Bul. No. 206, 1907. p. 4.
Mockeridge, F. A. Ann. Bot., London, Vol. 26, 1912. No. 113., pp. 871-897.

[2] Gerlach und Vogel. Cent. f. Bakt. Abt. II., Bd. 10, 1903. p. 638.
Hoffman, C. Cent. f. Bakt. Abt. II., Bd. 36. pp. 474-477.
Lipman, J. G. Ann. Rept., N. J. Exp. Sta., Bul. 29, 1908. p. 139.

[3] Paper 38 from the Laboratories of Plant Pathology and Bacteriology, Virginia Agr. Exp. Sta.

The soils used in the experiments, and their manner of collection, have all been set forth in the preceding paper. Suffice it to say that the soils retain the same number throughout these reports and the nitrification tests were made from the same sample and simultaneous with those which measured fixation.

It was decided that soil itself should be the medium in which nitrification would be measured, and the "nitrifying efficiency" method as proposed by Stevens and Wither[1] was adopted and used throughout the series of tests. The soil was first carefully sieved and then 400 grams weighed on a dry basis was placed in one litre Erlenmeyer flasks. To this was added 10 c. c. of sterile ammonium sulphate solution containing 240 milligrams nitrogen and the soil brought to 18 percent moisture content. Two flasks were set up for each soil and were kept in the incubator room at approximately 28° C. for six weeks, the moisture content being kept at 18 percent. At the end of this time nitrate determinations were made, usually by the Iron-Zinc Reduction method, or in cases where the nitrate content was low, the phenol-disulphonic acid method was employed. The results are reported on the basis of milligrams of nitrate nitrogen per 100 grams of soil.

All of the soils were subjected to another series of tests which may be termed " nitrate accumulation." Four hundred grams of soil were weighed out as before, but now into ordinary quart fruit jars. These samples were kept in the incubator room for six months at 28° C. and 18 percent moisture content. No ammonium sulphate was added and the nitrate present in the soils at the end of six months reflected the power of the soils to convert their own organic nitrogen into nitrate. The analyses at the end of this period were made by the phenol-disulphonic acid method.

Determination of the original nitrate content was made for all soils immediately after they were brought to the laboratory. These analyses showed extremely small quantities of nitrates present in the soils and in many cases only a trace was to be found. Yet these quantities, however negligible, were deducted from the amount found at the conclusion of the tests and all the figures represent increases in nitrate over that originally present. In Table I the results from all nitrification tests are presented. As in the fixation tests, 93 soils were examined, 88 of which were in pairs of a virgin and cultivated sample. In the table is shown the nitrifying efficiency of the various soils with 60 milligrams nitrogen as ammonium sulphate per 100 grams of soil and the accumulation of nitrate by the soils when kept under optimum conditions for six months. The figures are the averages from two flasks for each soil. The blank spaces indicate no nitrate.

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[1] Stevens and Withers. Studies in Soil Bacteriology. III. Cent. f. Bakt., Bd. 25, pp. 64-79. 1910.

TABLE I.—*The Nitrifying Efficiency of Various Soil Types With and Without Ammonium Sulphate.*

No. Soil Sample	Soil Type	Increase in mgs. Nitrate N. per 100 gms. soil with 60 mgs. $(NH_4)_2$ SO_4 after 6 weeks		Accumulation of Nitrate Nitrogen per 100 gms. soil after 6 months	
		Virgin	Cultivated	Virgin	Cultivated
1-2	Hagerstown Silt Loam	14.54	8.36	No Analysis	No Analysis
3	“ “ “	. . . .	7.2	“ “	“ “
4-5	“ Stony “	3.44	14.5	4	8.3
6	Hudson River Shale (Garden)	. . . .	46.76	. . . .	6.2
7-8	DeKalb Silt Loam	3.7	7.24	4	5
9-10	“ Stony “	9.15	5.24	3.7	1.44
11-12	“ Silt “	2.24	9.24	4.24	6.16
13-14	Hagerstown Silt Loam	12.25	20.7	4.52	9.6
15-16	“ “ “	1	22.4	6.64	5.6
17-18	“ “ “	. . . .	. . . .	4.8	2.72
19-20	Cacapon Sandstone	2	21.93	3.2	7.6
21-22	Devonian Shale	. . . .	19.58	1.92	2.6
23	“ “	. . . .	. . . .	. . . .	. . . .
24-25	Clay Loam	45.78	46.69	. . . .	. . . .
26-27	Sandy Loam	3.26	9.12	. . . .	. . . .
28-29	Cecil Clay	11.8	25.11	. . . .	. . . .
30-31	Clay Loam	5.5	40.39	1.8	.14
32-33	Iredell Clay	5.58	1.54	8.06	4.6
34-35	Cecil Loam	14.44	3.24	6.9	7.4
36	Cecil Loam (Meadow)	. . . .	13.38	8.06	. . . .
37-38	Loudon Sandy Loam	3.3	5.1	9.6	4.4
39-40	Cecil Clay	10.8	5.62	9.6	8
41-42	“ Loam	15.27	29.6	3.6	6.8
43-44	“ Sandy Loam	3	7.28	1.46	1.46
45-46	Iredell Clay Loam	7.42	3.36	2.4	2.2
47-48	Sandy Loam	.56	1.19	3.2	2.4
49-50	Clay Loam	. . . .	6.5	1.2	2.6
51-52	Norfolk Sandy Loam	. . . .	. . . .	2.4	1.2
53-54	Leonardtown Loam	. . . .	.6	2	6.6
55	Swamp	1.8	. . . .	10	. . . .
56-57	Black Clay	11.6	14.47	12	9.4
58-59	Norfolk Sandy Loam	3.78	2.1	1.6	1.6
60-61	Leonardtown Loam	14.86	4.69	6	6.4
62-63	Sandy Loam	. . . .	1.42	1.44	8.4
64-65	Cecil Clay	. . . .	13.3	1	2.2
66-67	Cecil Sand	2.7	1.5	9	4
68-69	Iredell Clay	1.88	1.86	5.2	6.6
70-71	Cecil Clay	1.58	1.58	13.6	7.6
72-73	Fine Sandy Loam	3.4	. . . .	6.6	4.8
74-75	Cecil Sand	. . . .	1.32	. . . .	4.4
76-77	Hagerstown Loam	5.8	30.41	10	9
78-79	Clay Loam	43.34	30.74	10	12
80-81	Cecil Clay	4.4	15.4	2.2	3
82-83	Hagerstown Clay	14.08	1.6	4.4	4
84-85	“ Loam	46.9	21.9	4.2	12
86-87	“ Sandy Loam	11.87	11.2	10	10
88-89	“ “ “	5.7	17.74	10	8.4
90-91	Edgewater Stony Loam	.6	2.4	4.8	3.8
92-93	Sandy Loam	. . . .	2.8	1.4	2.6

Considering first the influence which cultivation exerts on the nitrifying power of soils to which ammonium sulphate has been added, evidence is presented which shows that of the 44 pairs of virgin and cultivated samples, 27 gave higher nitrate formation by the cultivated soil; in 15 the virgin sample excelled; and in two there were no nitrates formed by either member of the pair. Comparing the total amount of nitrates formed by the two series, the cultivated soils show again a superiority over the virgin samples, and the average increase, when taking place in the cultivated sample, was 9.43 mgs. as compared with 6.98 mgs. in the virgin sample. Table No. II is given to summarize these points.

TABLE II.—*Comparative Nitrifying Efficiency of 44 Virgin and 44 Cultivated Soils after Six Weeks.*

Number of pairs in which cultivated soils excelled	27
Number of pairs in which virgin soils excelled	15
Number of pairs in which no nitrification took place	2
Total increase in nitrates by cultivated soils	489.27 mgs.
Total increase in nitrates by virgin soils	347.00 "
Average increase where cultivated soils excelled	9.43 "
Average increase where virgin soils excelled	6.98 "

The evidence which points to a more efficient nitrifying flora in cultivated soils than is present in corresponding virgin types is unmistakable. The process of cultivation undoubtedly tends to develop the nitrifying organisms chiefly, it may be supposed, through superior aeration which it affords. The relationship which is here brought out is very similar to that noted in the fixation tests, practically the same number of soils showing superiority of the cultivated samples. More significant still is the fact that the increases, when induced by the cultivated flora, average considerably higher than when resulting from the virgin flora which would indicate a higher degree of virulence of the bacteria which produced the respective processes as well as preponderance in occurence.

As was the case with the fixation tests an effort was made to trace a relationship between soil type and its influence on nitrification. Only the virgin soils were noted in this connection and the general classification of all the soils into five different types as previously made was used in the present instance. The nitrates formed by the virgin soils of these respective types were averaged and are presented in Table III.

TABLE III.—*Nitrifying Efficiency of a Number of Virgin Soils of Various Textures.*

Soil sample numbers	Classification	Average mgs. Nitrate Nitrogen per 100 gms soil
51, 53, 58, 60, 66, 72, 74 (7)	Fine Sandy Loam	3.46
19, 26, 47, 62, 86, 88, 92 (7)	Sandy Loam	3.18
1, 3, 4, 7, 9, 11, 13, 15, 17, 34, 37, 41, 43, 76, 84, 90 (16)	Loam	9.04
24, 30, 45, 49, 78 (5)	Clay Loam	20.5
21, 23, 28, 32, 39, 56, 64, 68, 70, 80, 82 (11)	Clay	5.61

There are some very striking differences to be noted in the foregoing table and, indeed, so noticeable are they that one might readily assume them to result in a large degree from soil texture. The results are from virgin soils, it will be recalled, and ammonium sulphate had been added to each sufficient to supply all the nitrogen necessary for conversion into nitrates. It would seem, therefore, that the nitrifiers were much less developed in certain soil types than in others. The open sandy soils are strikingly low, the loam and clay loam are as impressively high, and in the heavier clays again a falling off is evident. This latter decrease cannot be attributed to denitrification, since the control conditions of the experiment would scarcely admit this process. A condition which brought the averages of the sandy soils so low was due to some of the soils failing completely to nitrify and this was seldom true of the soils of heavier texture. Yet the failure of the former soils to produce nitrates was probably due to their lack of organic matter rather than to any inherent physical condition. The great majority of them are to be regarded as poor soils, low in humus, and deficient in those qualities which would develop a vigorous bacterial flora of any kind. Were these soils to be subjected to a well directed system of organic manuring they would, in all probability, as some of our own experiments indicate, assume a high place in nitrifying efficiency.

The heavy clay soils also are somewhat low in their nitrifying power. That aeration is essential to nitrification is too well demonstrated to question and these virgin clay soils had not the advantage of that condition to stimulate their nitrifying powers. The inhibiting effect of texture could likely be ameliorated by proper cultivation and there are indeed so many instances of this that it is probable that the undesirable condition may usually be overcome. Considering the natural powers of clay soils to nitrify, the results just cited show that, like extremely open sandy soils, the process is not so vigorous as in some of the other soil types.

The most satisfactory condition for nitrification, as exemplified by the results from this work, is that which is afforded by soils of the loam and clay loam types. The averages from nitrification tests in these soils are considerably in advance of the others. The conspicuous increase in the clay loam, from a relatively small number of soils it is true, is one of the most striking results recorded. Apparently in soils of this type, carrying a fair amount of organic matter, a condition for maximum nitrification is obtained.

The gradation in the nitrifying power of these virgin soils is extremely interesting—the scant formation of nitrates in sandy soils, the pronounced increase in loams and clay loams, and the depression of nitrification in heavy clay soils are indeed noteworthy.

In considering the influence of soil types on nitrification it will be well to inquire first how far cultivation will go in obliterating the differences which previously have been discussed. By singling out from Table I a number of cultivated soils which show high nitrifying powers, one from each of the five general classes, some idea may be obtained of the possibilities which each soil type presents. Such figures are presented in Table No. IV.

TABLE IV.—*Giving the Nitrifying Efficiency of a Number of Cultivated Soils of Various Types.*

No.	Soil Type	Mgs. of Nitrate Nitrogen increase per 100 grams soil
67	Cecil Sand	1.5
44	Sandy Loam	7.28
42	Cecil Loam	29.5
31	Clay Loam	40.39
29	Cecil Clay	25.11

The figures in Table IV are maximum results from cultivated soils of the respective types. The sandy soils are yet notoriously low, the loams and clay loam are high, the clay soil has responded to cultivation and presents a high nitrifying power. Although the maximum figure for sandy soils is low in the present investigation, such has not always been our experience with these soils. A previous report of a Norfolk soil which for five years received crimson clover turned under as green manure and yearly application of lime, showed a formation of 27.7 mgs. nitrate nitrogen per 100 grams of soil. It is possible, therefore, to develop soils of that type to a high degree of nitrifying power.

Of course the above results are from isolated cases and are not worthy of general conclusions. They are given merely to illustrate the possibilities which most soils probably possess from the standpoint of nitrification as promoted by the proper type of cultivation.

The relationship which nitrification and nitrogen fixation bear to one another was observed with interest throughout the present investigation.

The processes are both important factors in soil fertility; they doubtless respond to many of the same agencies; the degree of their activity is certainly one index to the crop producing power of arable lands. It would be logical to expect, therefore, that soils showing high nitrifying powers would exhibit likewise unusual qualities for fixation. For the sake of comparison a number of cultivated soils with outstanding properties in either process were chosen that the two qualities might be noted with reference to the same soil. These comparative figures are presented in Table V.

TABLE V.—*Comparing Certain Cultivated Soils, as to their Nitrifying and Nitrogen Fixing Power.*[1]

No.	Increase in Nitrate Nitrogen Mgs per 100 gms. soil	Increase in total Nitrogen per 10 gms. soil per 100 c. c. Ashby's Medium
5	14.5	10.76
6	46.76	3.5
14	20.7	14.08
16	22.4	14.4
18	.....	16.7 —
20	20.7	5 —
22	19.58	16.7
25	46.69	14.84
29	25.11	5.1 —
31	40.39	12.5
36	13.38	15.15
42	29.5	17.3
44	7.28	18.8 —
57	14.47	10.34
61	4.69	15.48—
63	1.42	10.6 —
65	13.3	10.27
67	1.5	16.45—
77	30.41	7.84—
79	30.74	8.6
81	15.4	5.49—
85	21.9	5.3 —
89	17.74	5.82—

The soils employed in Table V include all cultivated soils from Table I which produced as high as 13 mgs. nitrate per 100 grams soil and all those which fixed as high as 10 mgs. nitrogen per 10 grams soil in 100 c. c. Ashby's medium. The total number is 23 and of this number 11 showed nitrifying and fixation powers which may be regarded as commensurate one with the other. In the remaining 12 there is apparently no relationship between the two processes.

In the light of the above results there is no basis for assuming that nitrification and fixation are favored by the same influences; that they are susceptible to similar agencies of depression or stimulation. Apparently the two processes have little in common, for in 50 percent of the soils exhibiting an unusual power in the one process that same soil showed peculiar indifference to the other. Yet despite these results the authors are reluctant to assume such a position. It is at variance with the principles which are believed to regulate both nitrification and nitrogen fixation. It would be safer to ascribe such contradictions as those above to untrustworthiness of method than to conclude that two processes so intricately connected with soil fertility are unrelated. Perhaps in the great majority of our present cultivated soils, receiving as they do no especial treatment which would tend to develop either process, that neither proceeds with such vigor as would present opportunities for noting a relationship between the two. But soils which are unusual in their fertility, which have been intensely cultivated with reference to promoting those processes which govern productivity—in the great majority of these we necessarily expect a vigorous nitrifying and nitrogen fixing flora which are closely related in their activities.

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[1] The minus sign following a number indicates that the nitrifying and fixation powers of that soil do not appear to be correlated.

Referring once more to Table I the results from the nitrate accumulation tests are to be observed. These tests were made by keeping 400 grams of soil in glass fruit jars in the incubator room for six months at 28° C. and 18 percent moisture content. No nitrogen was added to the jars and the figures represent the conversion of original organic nitrogen into nitrates. Only one jar was set up for each soil. The results of these tests are summarized in Table VI in the manner of those in which ammonium sulphate was used.

TABLE VI.—*Giving the Comparative Accumulation of Nitrates in Certain Virgin and Cultivated Soils.*

Number of pairs in which cultivated soils excelled	19
Number of pairs in which virgin soils excelled	19
Number of pairs in which no nitrification took place	3
Total increase in nitrates by cultivated soil	217.02 mgs.
Total increase in nitrates by virgin soil	202.68 "
Average increase where cultivated soils excelled	2.8 "
Average increase where virgin soils excelled	1.99 "

In two of the pairs of soil the nitrates were the same and in one the analysis was lost.

The distinction in the nitrifying power of virgin and cultivated soils is not present here to the degree noted in the foregoing tests. The number of pairs in which the virgin soil excelled is the same as where the cultivated soil was highest; the total quantity of nitrate formed is slightly more in the cultivated soils than in the virgin; and the average increase is somewhat higher when induced by the former than when taking place in virgin soils. This condition of equality in nitrifying power of the two types of soils is probably due to the superior quantities of nitrogen originally present in the virgin soil—in 28 of the 44 pairs such was the case—and to the long period through which the tests ran allowing the slower action of the virgin soils to finally approach that of the cultivated ones. In 15 of the 19 pairs in which the virgin excelled the cultivated sample in nitrate accumulation, the organic nitrogen was higher in the virgin soil.

In yet another particular the present tests failed to confirm those with ammonium sulphate—in the accumulation of nitrates as regards soil type. On the basis of the classification previously used, averages from a number of soils of the same general type are given in Table VII.

TABLE VII.—*Nitrate Accumulation of a Number of Virgin Soils of Various Textures.*

Soils	Soil Type	Average increase mgs of Nitrate Nitrogen per 100 gms. soil after six months
(7)	Fine Sandy Loam	3.9
(7)	Sandy Loam	4.17
(14)	Loam	4.96
(5)	Clay Loam	3.06
(11)	Clays	5.07

The contradiction is in the case of the clay loams registering highest in nitrifying power with ammonium sulphate and lowest in nitrate accumulating power. The other results are in accord with those previously cited. It is difficult to explain such a discrepancy as this. Of course the validity of any comparison of the two series of tests is open to question—an inorganic nitrogen supply being used in the one case and an organic in the other, and the duration of the two experiments so widely different. Yet whatever correlation is obtained serves to strengthen the conclusions from each test. Nitrification at best is a process which is notorious for discrepancies even under ideal conditions for measuring it, and agreements which come about despite inequalities in methods are not unwelcome. The failure of clay loam to accumulate quantities of nitrate which correspond to their power of nitrifying ammonium sulphate belongs to that phase of nitrification which the authors would not attempt to explain.

Attention is to be called to the complete failure of certain soils to exhibit nitrification. In the tests with ammonium sulphate, 10 virgin and 4 cultivated soils exhibited this deficiency and 6 virgin and 5 cultivated soils failed to accumulate any nitrates through the conversion of their organic nitrogen. In Table I such soils are indicated by blanks in the columns containing the quantities of nitrates.

It is noteworthy that in most cases where the failure occurs it is true of both the virgin and cultivated soils of a pair. This quality of soils has often been reported, notably by Stevens and Withers,[1] and is not infrequently met with in studies on nitrification. Where it occurred in the present study, it was a characteristic of extremely poor soils and it is probable that only in such soils is the condition ever to be found.

SUMMARIZING DISCUSSION.

The studies on nitrification of ninety-three Virginia soils revealed some interesting facts regarding that process. Cultivated soils showed decidedly higher nitrifying qualities than virgin soils. This fact was exemplified in that twenty-seven of forty-four pairs of virgin and cultivated samples, the latter exhibited superior nitrifying powers, the average excess of nitrates was higher in cultivated soils than in the virgin samples, and the total nitric nitrogen was considerably higher from the cultivated soils.

There appeared to be considerable difference in the nitrifying power of virgin soils of various texture. This quality in the light open sandy soils was strikingly low, in the loams and clay loam it reached its maximum height, and in the heavy clays there was again depression, yet not so low as in the extremely open soils. The high nitrifying power of certain cultivated soils irrespective of texture, suggests however that this power may be largely increased by proper cultivation. The deficiency of light soils is probably due to a lack of organic matter; the depression in the clay soils could doubtless be ameliorated by aeration from tillage.

From the results of this investigation it is unwarranted to conclude that soils with high nitrifying power would exhibit also unusual qualities for free nitrogen fixation or vice versa. In 50 percent of the soils which were notably superior in either process such a relationship could not be traced, but in the remaining 50 percent there was close agreement in the vigor of the two processes.

The soils were examined also for their accumulation of nitrates over a period of six months. There was not exhibited in these tests the distinctive nitrifying superiority of cultivated soils over virgin soils as was evinced in the tests with ammonium sulphate, due perhaps to the higher organic nitrogen content of the virgin soils and the longer duration of the experiment. The clay loam failed in these tests to show nitrifying powers commensurate with those they exhibited with ammonium sulphate, though the relationship as regarded other soil types was quite consistent in the two series of tests.

A number of soils evinced no power whatever to nitrify. Some soils which failed to nitrify ammonium sulphate in six weeks accumulated quite significant amounts of nitrate from their own organic nitrogen in six months. On the other hand there were some which nitrified the inorganic medium and failed to accumulate nitrates. There appeared to be no relationship between the ability of a soil to nitrify the two types of media.

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[1] Stevens and Withers. Science. Vol. XXIX. No. 743, p. 506.

The Effect of Sand and Lime on Nitrification.[1]

The stimulation which lime offers nitrification is universally accepted as one of the most far reaching effects which it exerts on soil fertility. This fact has been shown by so many experiments that it no longer provokes intelligent controversy. Furthermore one phase of the beneficial activity usually ascribed to lime is a physical influence which it exerts on soils and which renders them open and friable, more easily penetrated by air, conditions which presumably favor nitrification. It is to be expected, therefore, that, other conditions being equal, soils of light open texture would have a higher nitrifying power than compact heavy soils. Working with this idea in view, an effort has been made in a few instances[2] to promote nitrification in clay soils by the addition of sand in various proportions. Comparative experiments with sand and lime are of interest, since each contributes something to the process of nitrification as influenced by the physical condition of the soil.

During the summer of 1914 an experiment was carried on at this station duplicating somewhat the work previously reported but introducing one new feature—an observation on the effect of adding one-fourth clay to an open sandy soil. These soil-types which have had extensive use here, were employed in the work: Albemarle and Appomattox Chocolate, both heavy clay soils, and Norfolk sandy loam, one of the light porous soils from Tidewater Virginia. The experiment was arranged in the greenhouse, using two gallon pots which received soil in the following order:

Albemarle Clay	Appomattox Chocolate Clay	Norfolk Sandy Loam
2 Controls	2 Controls	2 Controls
2 with one-fourth sand	2 with one-fourth sand	2 with one-fourth sand
2 with .15 percent $CaCO_3$	2 with .15 percent $CaCO_3$	2 with .15 percent $CaCO_3$
		2 with one-fourth clay

The same quantity of soil was added to each pot and all brought to 18 percent moisture content. That the rate of nitrification might be measured more strikingly, ammonium sulphate .1 percent was added to all pots. The experiment received the usual greenhouse care, the moisture content of the pots being kept uniform, and there was no condition which failed to influence all pots alike. At the end of the eight and twelve weeks, 500-gram samples were taken for nitrate analyses which were made according to the Iron-Zinc Reduction method. The results of the analyses from each pot are given in Table I.

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[1] Paper 39 from the Laboratories of Plant Pathology and Bacteriology, Virginia Agr. Exp. Sta.

[2] Reitmair: Zeitschr. f. d. Landw. Vers.—Wesen in Osterreich 11, 1908, p. 215.
Fred, E. B. Va. Agr. Exp. Sta. Ann. Rept., 1911-12, p. 185.

TABLE I.—*The Effect of Sand and Lime on Nitrification.*

Soil Types	Mgs. Nitrate N. per 100 gms. Soil	
	After 8 weeks	After 12 weeks
Norfolk Sandy Loam: Controls	8.7 8.02	20.8 20.8
" " " plus .15 percent $CaCO_3$	30.7	52.04 53.7
" " " " one-fourth Sand	4.1 6.8	14.83 13.07
" " " one-fourth Appomattox Choc.	9.4	20.84 20.66
Albemarle Clay: Controls	10.33 9.54	21.19 22.6
" " plus .15 percent $CaCO_3$	22.25	32.98 33.82
" " " one-fourth Sand	4.8 4.02	9.6 10.3
Appomattox Choc. Clay: Controls	15.5 16.3	29.48 35.92
" " " plus .15 percent $CaCO_3$	20.25 22.73	46.42 43.94
" " " " one-fourth Sand	11.89 12.91	23.32 24.5

A review of the foregoing table prominently asserts at least two facts—the enormous increase in nitrates under the influence of lime and the failure of sand to stimulate nitrate formation in clay soils. The actual depression of nitrification in the presence of sand which is true throughout the experiment is hardly to be expected. Such an influence would not unlikely be exerted on the Norfolk sandy loam, a soil which is well enough aerated in its natural condition, and the addition of sand would only dilute the organic matter present. Pure sea sand practically free from organic matter was used in the experiment and there was some loss in total organic matter wherever it was introduced. Yet this fact scarcely accounts for the falling off in nitrification, as nitrogen was abundantly supplied by the ammonium sulphate. In the control pots, which received no treatment whatever, nitrification proceeded more rapidly in the clay soils than in the Norfolk soil. On the other hand the use of lime was attended with uniformly better results with Norfolk soil than with the clays, and the maximum amount of nitrate found was in Norfolk soil with .15 percent $CaCO_3$ after twelve weeks. The more rapid formation of nitrates in heavy soils than in light open ones was reported as recently as 1911[1] and the notable response of Norfolk soil to lime has been often noted at this station. It would seem, therefore, that the action of lime in the present experiment is not to be attributed to any physical influence it exerted on the soil, and attempts to parallel such action—had it been achieved with lime—by the use of sand in clay soils were accompanied by an actual depression of nitrification. By adding one-fourth percent clay to Norfolk soil there was practically no increase in nitrification, yet no deleterious action was noted such as that reported by Pichard.[1]

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[1] Fischer, H. Landw. Jahrb. 41:755-822. 1911.

There are in the above analyses some slight variations in results from pots which received duplicate treatment. This is to be expected when such large quantities of nitrate are being measured. The differences between the pots which received different treatment are so well defined that it is easy to attribute it to the particular treatment each pot received. The variations emphasize, however, the fact that it is unwise to draw conclusions in nitrate tests on extremely small difference especially if large quantities of nitrates are involved.

The results in this paper are somewhat at variance with those published in the Annual Report of this Station, 1911-12[2] An increase in nitrification was noted therein under the influence of one-fourth sand when added to Albemarle and Appomattox chocolate soils, the former giving with sand a maximum increase over the control of 2.8 mgs. per 100 grams of soil and the latter 7.5 mgs. The experiment which showed these results was started in November, 1911, and no increase from the sand was observed until April of the following year. From that date until September the increase was observed. As the present experiment ran from May to August, 1914, the period of active nitrification was practically the same in both experiments. The variations can only be explained by the difference in time which the two experiments ran, yet admitting this factor the results on this point are somewhat irreconcilable.

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[1] Compt. rend. (Paris), 109, 1889. pp. 455-447.
[2] P. 185.

7

HATCH EXPERIMENT STATION

OF THE

MASSACHUSETTS AGRICULTURAL COLLEGE.

BULLETIN NO. 97.

A FARM WOODLOT.

MAY 1904.

The regular Bulletins of this Station will be sent free to all newspapers in the State and to such individuals interested in farming as may request the same. Technical Bulletins are sent only to those persons interested in the subject treated of in each case.

AMHERST, MASS.:
PRESS OF CARPENTER & MOREHOUSE
1904.

HATCH EXPERIMENT STATION

OF THE

Massachusetts Agricultural College,

AMHERST, MASS.

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The co-operation and assistance of farmers, fruit-growers, horticulturists, and all interested, directly or indirectly, in agriculture, are earnestly requested. The Bulletins will be sent free to all newspapers in the State and to such individuals interested in farming as may request the same. General bulletins, fertilizer analyses, analyses of feed-stuffs, and annual reports are published. Kindly indicate in application which of these are desired. Communications may be addressed to the

Hatch Experiment Station, Amherst, Mass.

A FARM WOODLOT

FRANK A. WAUGH.

There is at present a widespread interest in forestry, though this interest is nowhere greater than the imminent importance of the subject justifies. On the other hand it is quite plain that many of our resources, public and private, state and national, are being shamefully wasted because of the ignorance or carelessness of the principles of forestry. It becomes a public duty, therefore, for anyone who has even an elementary knowledge of the subject, or who possesses even a modicum of practical information, to spread this knowledge or information for the general welfare.

One thing greatly needed in current forestry discussions is concrete knowledge of forest facts and of forestry operations. Too much of the common talk on the subject stops with general principles, (which are mostly unintelligible when they are unconnected with concrete examples), or even contents itself with the fervent assertion that forestry is a good thing and ought to be encouraged.

It is the purpose of this bulletin to set forth a single definite concrete example of practical forestry under conditions typical of nearly the whole State of Massachusetts and of large areas in neighboring States. The problem in hand is that of the ordinary farm woodlot, and the conditions are those prevalent on a majority of New England farms.

The woodlot in question belongs to the Department of Horticulture of the Massachusetts Agricultural College, and has been for many years subjected to the same conditions, the same demands, and, for the most part, to the same unsystematic management as any farm woodlot. It has been called upon for stove-wood, fencing, rough lumber, etc., and has not been made the theater of any general experiment in scientific systems of forestry. There have been some plantings of forest trees, however, in which particular the conditions are not typical of the common farm woodlot. The tract contains 12½ acres of good land. In respect to the quality of the land the situation is not exactly typical; for the farm woodlot ought to occupy waste land, while this tract, if cleared, would be prime orchard or garden land. It occupies the top and north and west slopes of a small hill or drumlin.

Products required.—The woodlot in question is expected to produce stove-wood, fence posts, and dimension lumber. Recently there have been some calls upon it for box lumber. These requirements are practically the same as will be found on any other farm. The stove-wood is easily secured from necessary thinnings, the removal of dead trees, etc., and may be looked upon as entirely a waste product. According to our experience the removal of stove-wood does not any more than pay for the work required—sometimes less than that. It is altogether probable that there is very little land in the State where stove-wood can be grown and harvested at a profit. If a woodlot yields nothing better than this, its owner can make money by giving it away.

Fence posts and stakes are always in demand on a farm. On this farm they are largely used for making grape trellises, staking up bush fruits, etc. They are worth considerably more than fire wood, and are a trifle harder to produce, yet may be taken in quantity from any fairly well managed woodlot. In our own case we find American larch one of the best species for producing this class of material. Several of the photographs show the larch trees, which of course were planted in this situation.

Dimension lumber can be secured from any straight, clear, forest-grown trees of reasonable sizes. In our wood we find chestnut and hemlock the most productive, with oak and maple standing second. We have no large white pine, which might easily be one of the best. In the production of good dimension lumber, real forest conditions are required and some length of time is necessary. The trees must stand close enough together to make clean, straight trunks. They should be culled out as fast as they reach maturity, and frequently certain trees have to be cut before absolutely mature in order to favor other trees or to improve the forest composition.

Box lumber is required on our farm in making boxes for marketing fruit and vegetables, and for making greenhouse flats. Any fairly clear soft wood will answer. Hemlock does well and even poplar is good. The harder and more valuable kinds of lumber may well be saved for more honorable uses.

Species of Trees.—The varied requirements of almost any farm make it desirable to have several different kinds of trees growing in the woodlot. In this respect our own lot is a model. We have more than mere samples of the following species : chestnut, white oak, red oak, hard maple, yellow birch, white birch, larch (often known as tamarack), Scotch pine, and hemlock. There are small quantities of other species. For example there is considerable small growth of white pine, a few black cherry, sassafras, etc. This mixture of species is encouraged, both because it is easier to manage (under farm conditions) and because it furnishes a variety of forest products.

Mixture of Species.—We have just said that the mixture of species is easier to manage than any one species alone. This is probably untrue as a general principle applied to large forest areas, and there are undoubtedly some exceptions even in the conduct of farm woodlots. Nevertheless the growth, exploitation and reproduction ot pure woods—that is areas covered with one species only—does not seem to meet the conditions existing on the ordinary farm.

If several species are to be mixed, however, it is obvious that great care should be taken in making up or in controlling the mixture. Some species are much more valuable than others and the most valuable ones should be given the preference ; and some species will thrive in company while others will not. With respect to the former principle it is to be noted that ordinary farm management (or mismanagement, in this case) often secures a result exactly the opposite of that desired. The careless man cuts always the trees best suited to his immediate needs,—that is the best trees in the forest,—leaving the poorer ones to survive and perpetuate themselves. With respect to the second principle it may be remarked that to make the best theoretical mixture of species requires a considerable knowledge of forest species and technical forest principles. This is a matter which space now forbids us to enter upon.

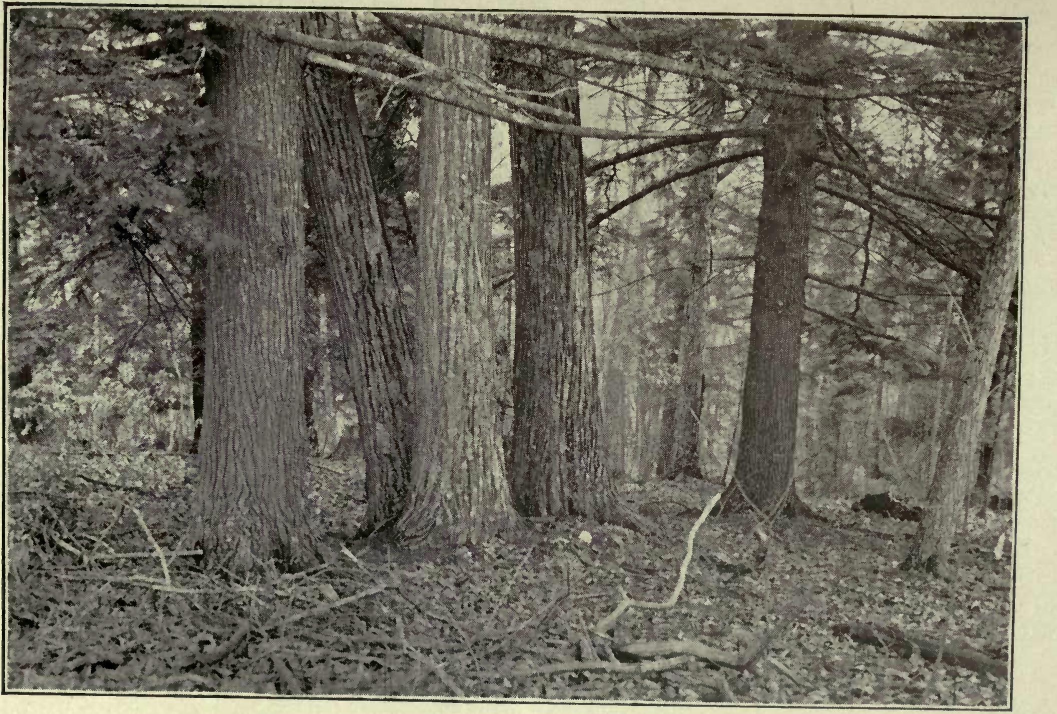
Reproduction and succession.—One of the commonest shortcomings in farm management of woodlots is that the trees are cut without regard to their reproduction. Constant foresight should be had to the future composition of the woodlot. The valuable species should be encouraged. Pines and hemlocks should be allowed to bear seed. Young oak seedlings should be favored. A good growth of oak can sometimes be secured from sprouts coming up from stumps (coppice reproduction). Chestnut reproduces itself vigorously in this way, especially where young trees are cut close to the ground.

It will be noticed also that some species follow each other in a definite succession. On waste land, recently cut over areas, or abandoned farm fields, birch and poplar are usually the first to appear. As soon as these trees have formed a forest cover, have begun to shade the ground, other species come in. Pines, oaks, and hemlocks belong to this second crop. Comparatively worthless species may thus be taken advantage of to secure the establishment of better ones.

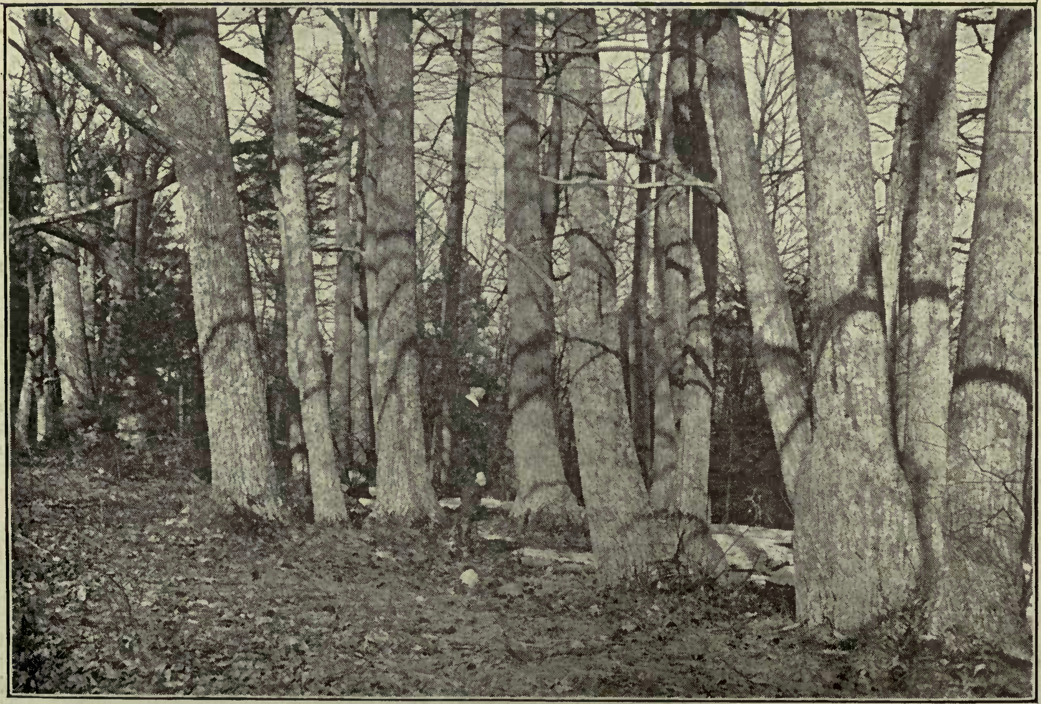
Improvement cuttings.—As already hinted, cuttings are to be made not with sole regard to the wants to be immediately supplied. The trees selected for removal should be chosen largely with reference to the trees which remain. The stand of timber should be kept fairly uniform, not so thick as to kill out good-sized trees, and not so thin as to allow heavy side branches to grow. Where two good trees are unduly crowding each other, one of them should be removed. In deciding which tree shall go and which shall stay the question is not so much which will make the best lumber now as which will make the best growth in the next ten or twenty years. If the future is kept thus consistently in mind it will seldom be necessary to make any extensive " improvement cuttings " just for the sake of helping the woodlot. Every tree taken out will represent an improvement cutting.

Plantings.—The typical woodlot, and the sort by far the most common in New England, consists of a natural forest. If it is properly managed it will reproduce itself indefinitely. No tree planting is necessary. In many places, however, even in Massachusetts, tree-planting is necessary, practicable and profitable. Our own woodlot contains both natural woods and planted areas. There is one lot of planted white birch fifteen years old. See plate 12. There is another area planted with Scotch pines and larch mixture twenty-five years old. See plate 9. One of the best artificial plantations is of pure larch twenty-four years old. Another smaller plantation of larch is seventeen years old. These trees were set in rows 4 feet apart, with trees about 2 feet apart in the rows. They have done very well indeed and are already producing valuable timber. See plates 10 and 11. It is entirely plain that forest plantations of larch and pine can be successfully made on our soil.

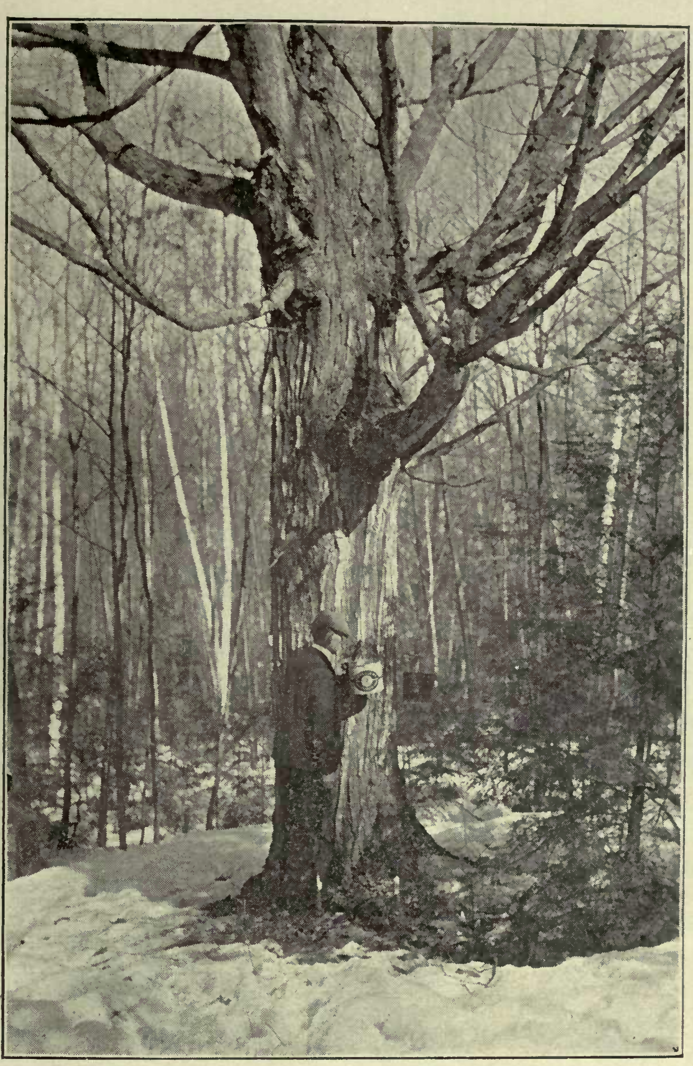
In conclusion we invite special attention to the photographs which really show more of the actual forest conditions than can be told in words. Each one is a lesson in itself. Yet, as for that, thoughtful observation of growing forests anywhere will always bring important facts to light; and if this brief bulletin shall arouse the reader to such interest and observation, its principal object shall have been fully served.



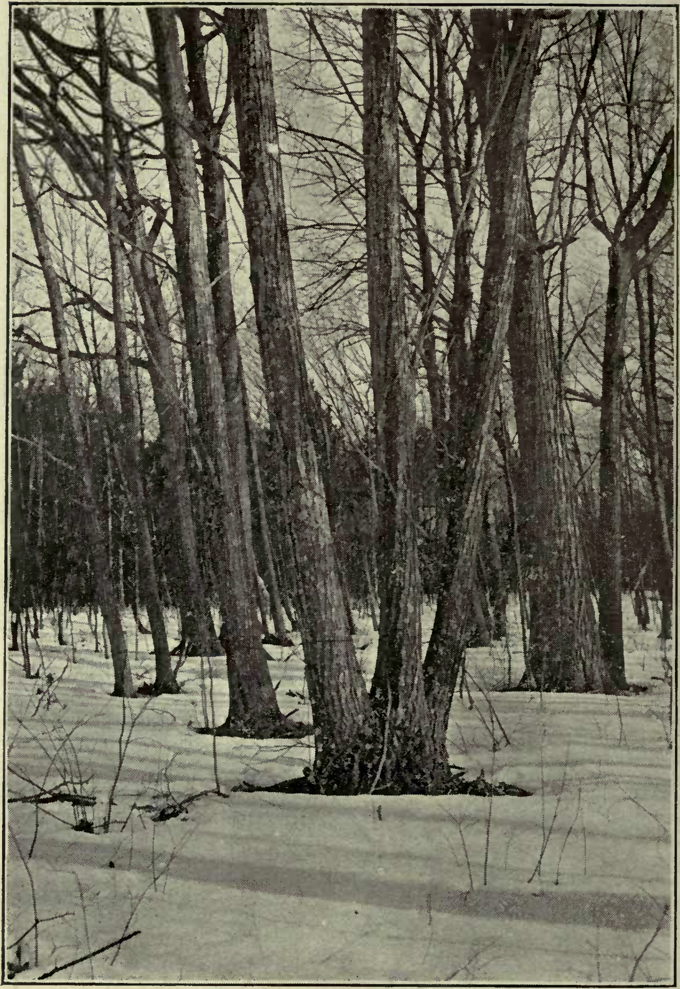
1. **Mature Forest.** Old Hemlocks and Chestnuts, crowding. The three Chestnuts in the middle should be taken out. They are mature, and will make good sawlogs.



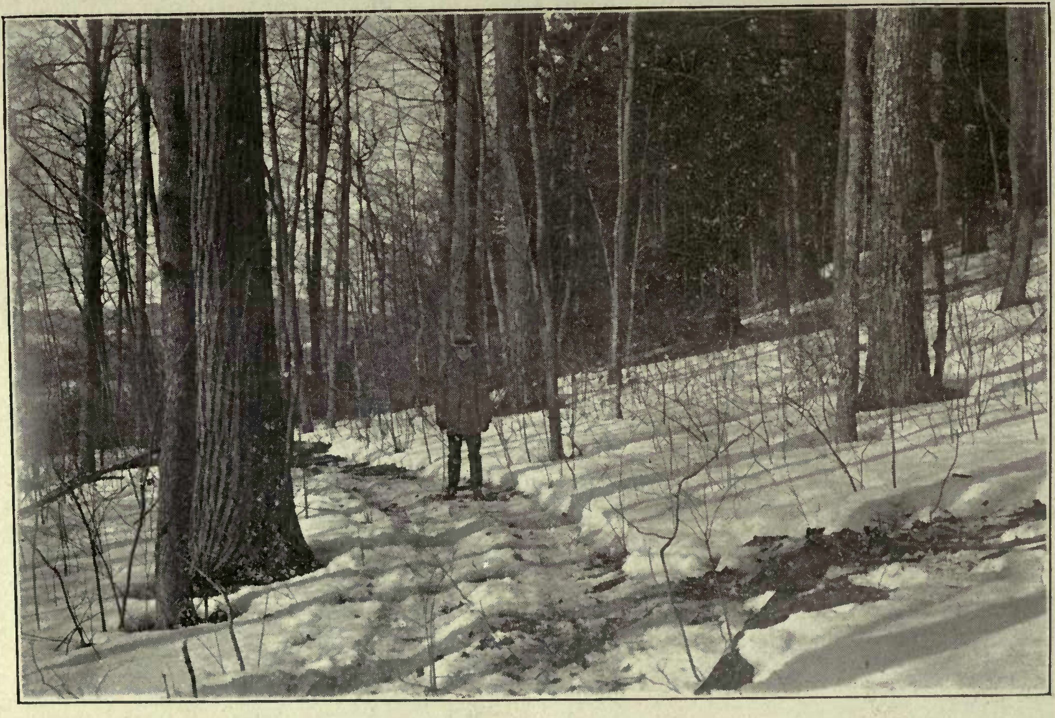
2. **Chestnut, Second Growth.** Mostly sprouts from stumps. These should be thinned. There are a few sawlogs and several railroad ties here.



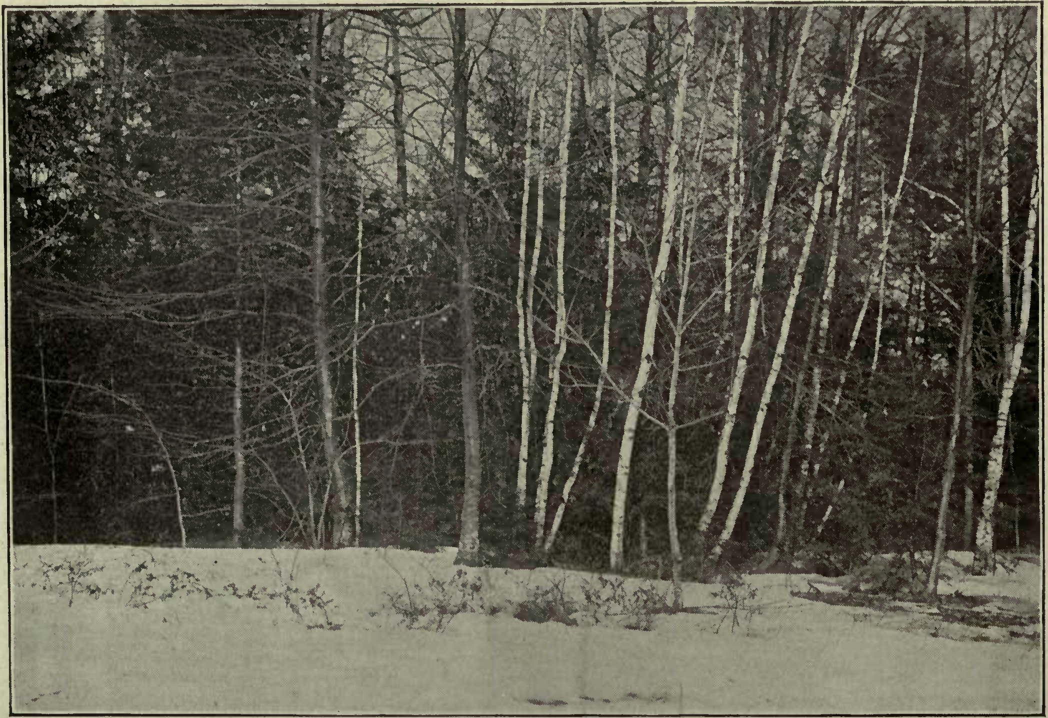
3. **Old Sugar Tree.** From the standpoint of the forest, this tree should have come out several years ago. It is quite proper, however, that the farm woodlot should produce syrup or sugar, and with such a purpose in view old sugar trees would be retained.



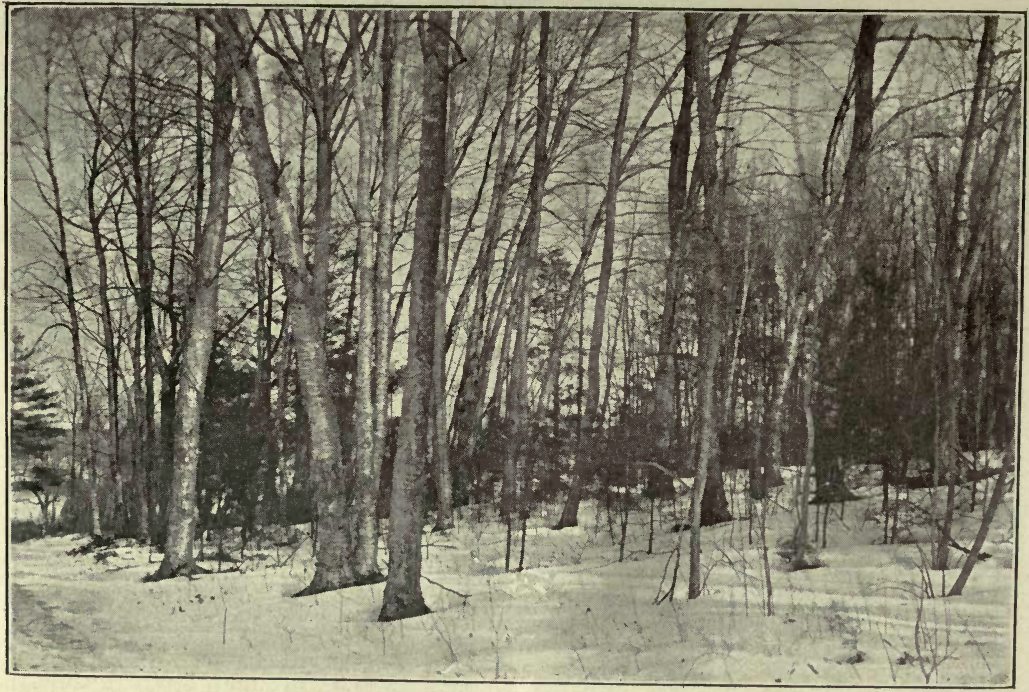
4. **Young Chestnut.** Mostly coppice growth, showing the vigorous reproduction when young chestnut is properly cut. A little thinning would be in order here. A few telephone poles could be cut.



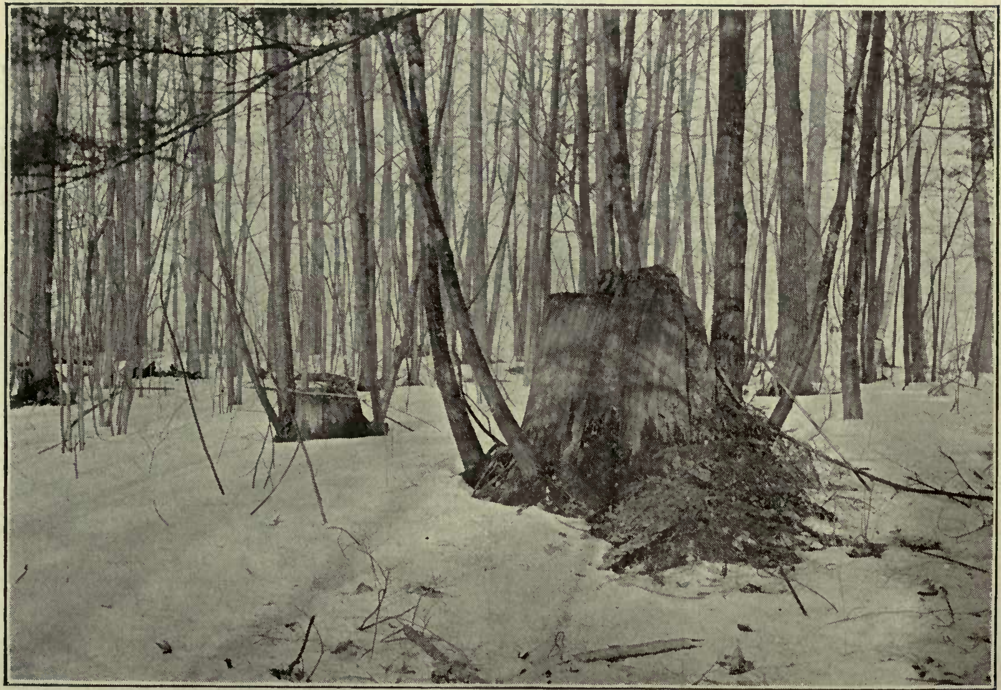
5. **Mixed Forest.** The large Chestnuts near the left and right sides of the picture should be removed. They are practically mature, and should make room for the younger trees beside them.



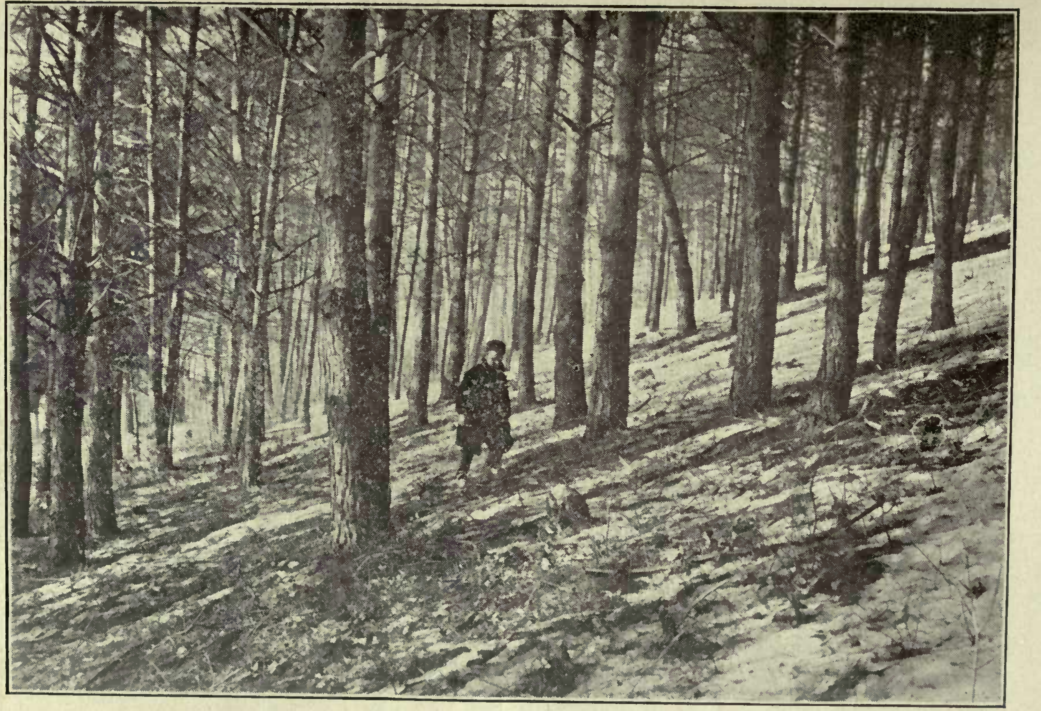
6. **Natural Reproduction.** Hemlock coming in under the shade of young birch. Showing the vigorous natural reproduction of forest under suitable conditions.



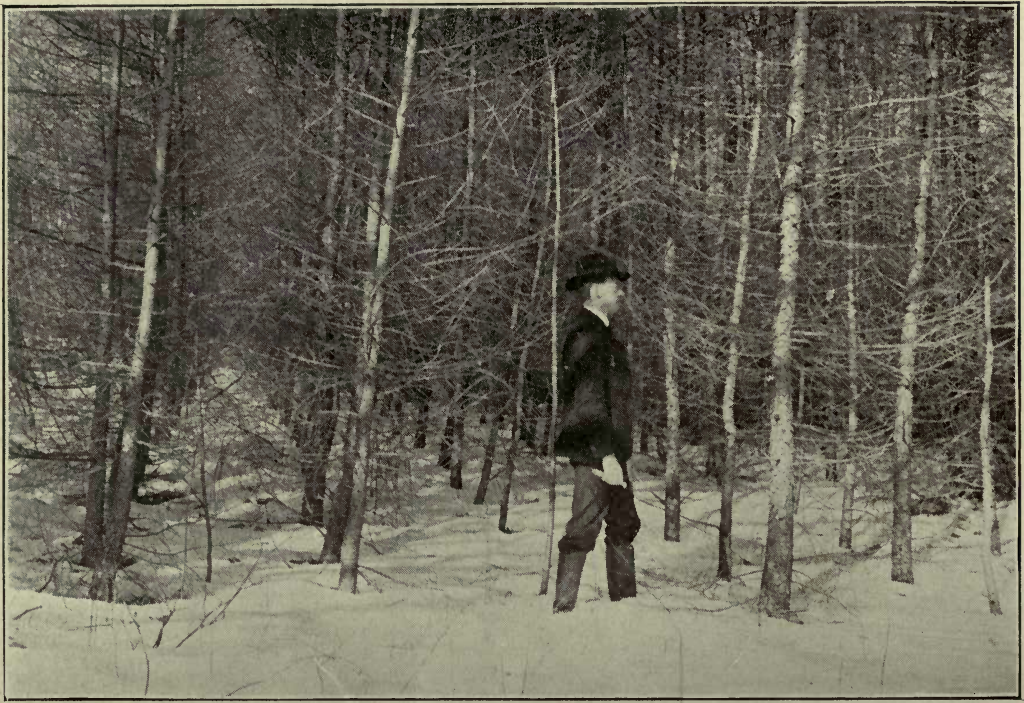
7. **Yellow Birch and White Pine.** The pine is coming in from natural seeding under the birch. The birch can be gradually thinned to make room for the pine.



8. **Young Second Growth Forest.** Chestnut, oak and maple mixed. The large stump shows how chestnut ought NOT to be cut.

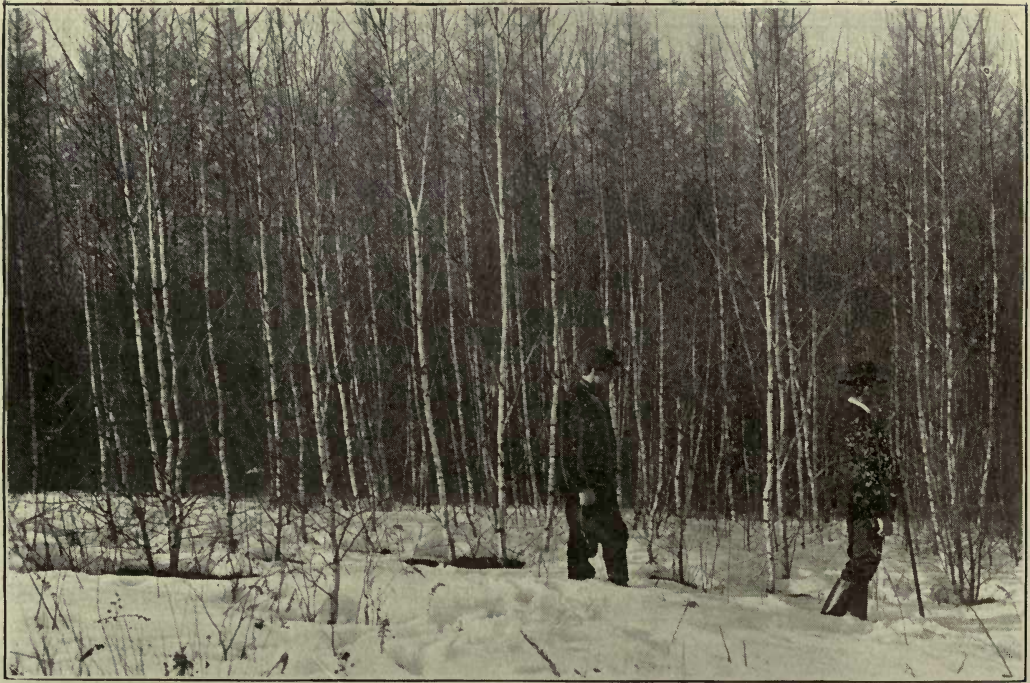


9. **Scotch Pine and American Larch.** These trees were planted out 25 years ago, and have been pruned and thinned. White pine would doubtless have been better than Scotch pine.

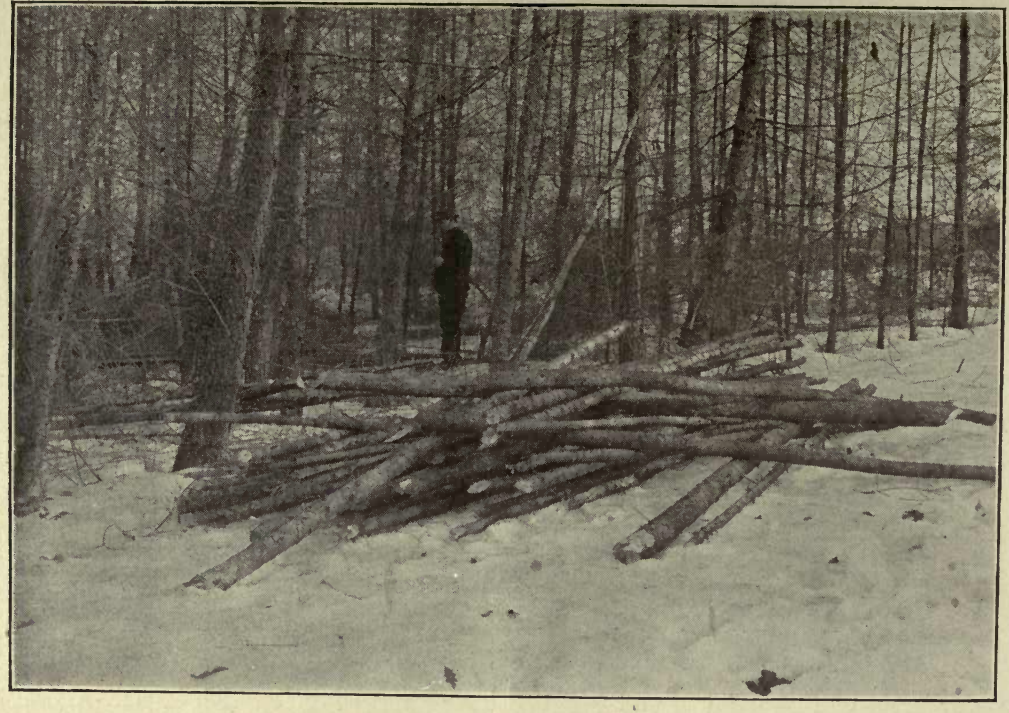


10. **American Larch.** A thick plantation about 17 years old. Now ready for thinning. Will furnish fence posts, grape stakes, etc. In a few years the larger trees would make telephone poles.

11. **American Larch.** Trees planted about 25 years ago. Some thinning would now be in order. The trees to be taken out will make good fence posts.



12. **Plantation of White Birch.** These trees, now about 15 years old, are not valuable except as nurse trees for other species. Underplantings of pine or hemlock would probably be successful here.



13. **Thinning Larch.** Showing the poles taken from a plantation of American Larch 25 years planted. The poles are about 20 feet long and average 5 inches in diameter at the butts.

The Following Bulletins are Available for Distribution to Those Who May Desire Them.

No. 27. Tuberculosis in college herd: tuberculin in diagnosis; bovine rabies; poisoning by nitrate of soda.
No. 33. Glossary of fodder terms.
No. 35. Agricultural value of bone meal
No. 41. On the use of tuberculin (translated from Dr. Bang).
No. 54. Fertilizer analyses.
No. 57. Fertilizer analyses.
No. 64. Analyses of concentrated feed stuffs.
No. 67. Grass thrips; treatment for thrips in greenhouses.
No. 68. Fertilizer analyses.
No. 70. Fertilizer analyses.
No. 72. Summer forage crops.
No. 75. Fertilizer analyses.
No. 76. The imported elm-leaf beetle.
No. 77. Fertilizer analyses.
No. 78. Concentrated feed stuffs.
No. 79. Growing China asters.
No. 81. Analyses of fertilizers and manurial substances, instructions to manufacturers, agents, etc.: discussion of trade values; treatment of barnyard manure with absorbents.
No. 82. Orchard management: cover crops in orchards; pruning orchards; report on fruits.
No. 83. Fertilizer analyses.
No. 84. Fertilizer analyses.
No. 85. Concentrated feeds.
No. 86. Orchard treatment for the San José scale. One year's experiments in Massachusetts.
No. 87. Cucumbers under glass.
No. 89. Fertilizer analyses.
No. 90. Fertilizer analyses.
No. 91. Injuries to shade trees from electricity.
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TEXAS AGRICULTURAL EXPERIMENT STATION

BULLETIN No. 171 DECEMBER, 1914

DIVISION OF CHEMISTRY

LOSSES OF MOISTURE AND PLANT FOOD BY PERCOLATION

PROPERTY OF DIVISION OF
FORESTRY
COLLEGE OF AGRICULTURE
UNIVERSITY OF CALIFORNIA

POSTOFFICE:
COLLEGE STATION, BRAZOS COUNTY, TEXAS

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Austin, Texas
1915

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BY

G. S. FRAPS, Ph. D., Chemist

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*As of November 30, 1914.
†In cooperation with United States Department of Agriculture.

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LOSSES OF MOISTURE AND PLANT FOOD BY PERCOLATION

BY G. S. FRAPS, PH. D., CHEMIST.

Certain fundamental conditions are essential to plant life. These include light, water, favorable temperature, favorable soil conditions, and plant food. A deficiency of any one of these will limit the growth of the plant. From the standpoint of plant nutrition, no one is more important than the others. From the viewpoint of the farmer, however, the important conditions are those which, under ordinary agricultural conditions, may be deficient and so control the growth of the plant and the crop produced, and which, being deficient, may be supplied, to a greater or less extent, or the deficiency controlled, by the farmer. In other words, the practical farmer is not much concerned with conditions beyond his control which limit plant growth, or those which are favorable under ordinary agricultural practice. He is much concerned, however, with deficiencies which he can correct or control. Temperature and light are little subject to control in agricultural practice, but water, soil conditions, and plant foods ordinarily deficient—phosphoric acid, nitrogen and potash—are more or less subject to control. The quantity of rainfall cannot be regulated, but the amount of water stored in the soil and that lost by evaporation may, more or less, be modified by agricultural practices.

QUANTITY OF WATER NEEDED.

The quantity of water needed by the plant depends upon conditions, but is very large. According to estimations of King, corn requires 233 to 272 pounds of water to produce one pound dry matter. This does not refer to the grain but to the entire plant. Barley requires from 262 to 774 pounds of water to produce one pound dry matter, and red clover from 249 to 453 pounds. The quantity estimated by different investigators varies, but we can assume, as a basis for calculation, that one pound of dry matter requires 300 pounds of water. This quantity of water is taken up by the roots of the plants and evaporated through their leaves. An additional quantity of water is lost by evaporation from the soil, during the period of growth of the plants.

The amount of water required by plants* depends upon several conditions:

(a) Dryness of the air. Plants evaporate more water into a dry atmosphere than into a moist.

(b) The water in the soil. Plants evaporate more water from a soil when wet than from the same soil when it contains a fair quantity of moisture.

(c) Light. More moisture is used in light than in darkness.

(d) Fertility of the soil. Plants use less water when grown on a fertile soil than when grown on a poor soil. The addition of needed plant food to a poor soil decreases the consumption of water. Hence, the use of the proper kind of plant food will economize water. For example, the Nebraska Experiment Station found that corn grown on a poor soil used 540 pounds of water for each pound of dry matter produced. When same soil was manured, corn used only 350 pounds water per pound of dry matter produced.

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*Fraps, Principles of Agricultural Chemistry, p. 120.

(e) Variety of plants. Different varieties vary considerably in their requirements for water.

If we estimate that it requires 300 pounds water to produce 1 pound dry matter, to be evaporated by the plant, the following are the approximate quantities of several crops which would be produced per acre by one inch water (227,000 pounds) used by the crop:

Cotton, pounds, lint	80
Corn, bushels	6
Wheat, bushels	4
Oats, bushels	9
Alfalfa, pounds	760
Hay, pounds	760

The supply of water is undoubtedly, at various times, the controlling condition of plant growth, and unfavorable moisture conditions often have their effect upon crop production. Methods for decreasing the effect of unfavorable moisture conditions are, therefore, of great advantage in practical agriculture.

WATER AVAILABLE TO CROPS.

The amount of water at the disposal of the crop will depend upon:

(1) The quantity of available water in the soil at the beginning of the growing season.

(2) The amount and distribution of rainfall during the period of crop growth.

(3) The loss from the soil by evaporation from its surface.

(4) The loss of the rain water which runs off on the surface of the soil.

(5) The loss from water which passes through the soil and into the ground water.

The quantity of available water present in the soil at the beginning of the growing season depends, in turn, upon a number of conditions. These include: (a) Character of soil, (b) depth of soil, (c) character and depth of subsoil, (d) rooting habits of the plant, (e) quantity and distribution of the previous rainfall, (f) previous treatment of the soil.

The character of the soil determines the amount of water it will hold when saturated, its readiness to lose water by evaporation or percolation, and the quantity of water which, though present, is held so firmly that plants cannot take it from the soil.

The depth of the soil, together with the depth of the subsoil, determines the volume of soil from which water may be drawn. It is obvious, for example, that when plant roots can occupy eighteen inches of the soil, they have more water at their disposal than when they occupy only twelve inches of the same soil. The depth and character of the subsoil affect the soil volume occupied by the plants, the quantity of water retained in the subsoil, and the quantity of water which can be moved by soil forces, from areas below the roots, to within reach of the roots.

The rooting habits of the plant determine, to a certain extent, the soil volume which the roots will occupy. There is a great difference in plants in this respect. In arid climates, plants seem to send their roots deeper than in humid sections.

The quantity and distribution of the previous rainfall determines the degree of saturation of the soil at the time of planting. The soil may, or may not, be saturated at this time. In some sections, it is usual to speak of having "a good season in the ground," meaning thereby that the previous rains have placed the soil in a good condition of saturation at the time of planting the crop.

The previous treatment of the soil may have some effect upon the depth of rooting of the plant and thus on the soil volume occupied. Subsoiling may, with certain soils, be of advantage in this respect. The previous treatment will also determine, to a certain extent, whether the winter rains sink into the soil or run off on its surface. It will also determine whether the soil has been in good condition to absorb the rains, and will affect the losses of water by evaporation. Shallow surface cultivation, previous to planting the crop, may be needed for the purpose of conserving soil moisture. Fall plowing may be needed to open the soil to the winter rains. On the other hand, fall plowing of other soils may be a disadvantage. Spring plowing may be all right on some soils and in some seasons, but, under other conditions, it may cause loss of moisture through the drying out of the soil.

It is not our purpose to discuss fully any of the factors above mentioned.

The amount and distribution of the rainfall during the period of growth of the crops affect not only the quantity of water which penetrates into the soil and the quantity which runs off, but also the length of the period between rains governs the length of the time during which the plant must rely upon the store of water in the soil.

The loss of the rainwater which runs off from the soil surface depends on the slope of the soil, the condition of its surface, and the character of the soil. The average run-off, due to the average precipitation, is considered to be approximately as follows:*

Rainfall.	Run-off on	
	Steep slopes.	Gentle slopes.
5 inches	0 inches	0 inches
10 inches	2 inches	0 inches
15 inches	4 inches	1 inch
20 inches	8 inches	3 inches
25 inches	12 inches	4 inches
30 inches	17 inches	8 inches
35 inches	22 inches	12 inches
40 inches	28 inches	15 inches
45 inches	....	20 inches

---

*Wilson, Irrigation Engineering.

The run-off in dry climates is less than in humid. It is, of course, difficult to estimate accurately the run-off from cultivated lands. The above figures may be an aid in forming an estimate. The run-off also depends on the rate of precipitation. There will be more run-off from a precipitation of one inch during three hours than from the same quantity during forty-eight hours.

PERCOLATION APPARATUS.

A percolation apparatus consists of a definite area of soil enclosed in a water-tight receptacle, with an outlet tube at the bottom, and a vessel to receive the water which percolates. All the water which falls in this apparatus must either evaporate or percolate through the soil. There is no run-off. In some experiments, plants have been grown in such vessels. Percolation apparatus are in use at the Rothamsted, England, Experiment Station, at the New York Cornell Station, and at the Florida Station. Other investigators and experiment stations have also carried out experiments with this form of apparatus.

Description of Apparatus.—The percolation apparatus used in this work consists of 48 galvanized iron cans 12 inches in diameter and 24 inches deep, with a block tin tube at the bottom. These cans are buried in the ground. Figures 1 and 2 are drawn to scale, and show the arrangement of the apparatus. The cans are connected with the bottles to receive the water by means of a tight cork. The apparatus was set up and filled with soil in March, 1910. Six pots were filled with each soil. Each pot of the same soil receives a different treatment. Each of the pots received first ten pounds of washed gravel, which filled them to a depth of one and one-half inches. The subsoil and surface soil were then placed in them. The first forty-two pots were filled in the middle of March, 1910. The last six pots were filled about ten days later. As the earth settled considerably, further additions of soil, to the amounts shown in the table below, were made on May 24, 1910. The soil was in all cases in a moist condition as it was received from the field.

On account of various difficulties and for the purpose further of allowing the soil to settle and assume more or less its natural condition, the percolation waters were not collected until January 1, 1911. At the end of December, 1910, a heavy rainstorm set in, which saturated the soils thoroughly; they therefore went into the experiment in a saturated condition.

The following table shows the quantities of the soil added to the pots:

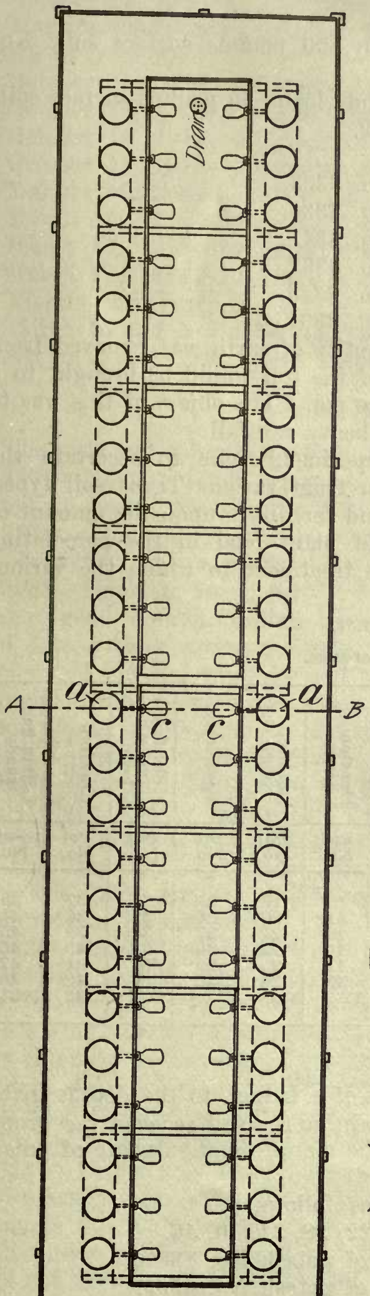
Pots Nos. 1-6 inc.—Norfolk sand, surface soil about 117 pounds, No. 2377.

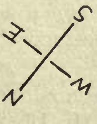
Pots Nos. 7-12 inc.—Orangeburg fine sandy loam, 110 pounds, No. 2378.

Pots Nos. 13-18 inc.—Houston loam, 57 pounds surface soil, No. 3333; 57 pounds subsoil, No. 3334.

Pots Nos. 19-24 inc.—Houston black clay, 45 pounds surface soil, No. 3335; 45 pounds subsoil, No. 3336.

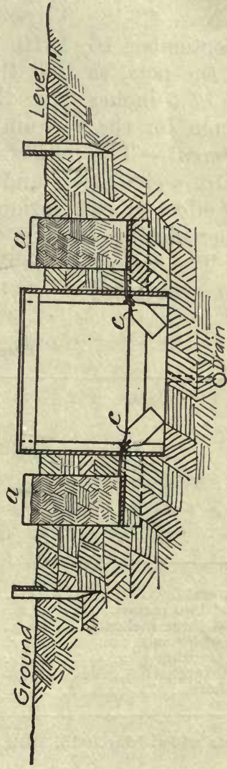
Pots Nos. 25-30 inc.—Yazoo clay, 47 pounds surface soil, No. 3341; 47 pounds subsoil, No. 3342.





TOP VIEW OF PERCOLATION PIT

Scale 12"



SECTION OF PERCOLATION PIT AT A-B

Scale 12"

Pots Nos. 31-36 inc.—Miller fine sandy loam, 56 pounds subsoil, No. 3337; 56 pounds surface soil, No. 3338.

Pots Nos. 37-42 inc.—Crawford clay, 50 pounds surface soil, No. 3343; 50 pounds subsoil, No. 3344.

Pots Nos. 43-48 inc.—Lufkin fine sandy loam, 55 pounds surface soil, No. 3631; 55 pounds subsoil, No. 3632.

Additions May 24, 1910:

Pots Nos. 13-18—35 pounds soil No. 3333.
Pots Nos. 19-24—15 pounds soil No. 3335.
Pots Nos. 25-30—12 pounds soil No. 3341.
Pots Nos. 31-36—33 pounds soil No. 3337.
Pots Nos. 37-42—10 pounds soil No. 3343.
Pots Nos. 43-48—33 pounds soil No. 3631.

On September 16, 1910, a small quantity of earth was removed from each of the pots, so that the surface of the soil would be brought to a distance of 3 inches from the top of the pot. The object of this was to allow room for the accumulation of a heavy rainfall.

Treatment.—The objects of the experiment were to ascertain the amount of percolation and evaporation from various Texas soil types, and the effect of cultivation, manure and fertilizers upon the amount of water percolating and on the losses of plant food in the percolating water. The following table shows the treatment to which the various pots were subjected:

TABLE NO. 1.

Plan of Treatment of Pots.

Treatment.	Norfolk sand.	Orangeburg fine sandy loam.	Houston loam.	Houston black clay.	Yazoo clay.	Miller fine sandy loam.	Crawford clay.	Lufkin fine sandy loam.
	Pot No.	Pot No.	Pot No.	Pot No.	Pot No.	Pot No.	Pot No.	Pot No.
No treatment	1	7	13	19	25	31	37	43
Cultivated two inches	2*	8*	14*	20*	26*	32*	38*	44*
Cultivated three inches	3	9	15	21	27	33	39	45
Sulphate of potash	4	10	16	22	28	34	40	46
Manure, October 15	5	11	17	23	29	35	41	47
Manure, March 15	6	12	18	24	30	36	42	48
Soil numbers	2377	2378	3333	3335	3341	3337	3343	3631

*Nitrate added March 15, 1912.

The cultivation was done by means of a trowel, to the depths given, every week, and as soon after every rain as the soil reached the proper condition. The pots which received the manure and sulphate of potash were not cultivated.

Additions.—Additions were made as follows:

Potash additions to pots 4, 10, 16, 22, 28, 34, 40, 46.
October 15, 1910—1 gm. sulphate of potash No. 13274.
October 15, 1911—1 gm. sulphate of potash No. 4563.
March 15, 1912—2 gm. sulphate of potash No. 4563 to 4, 10, 16, 22.
March 15, 1912—4 gm. sulphate of potash No. 4515 to 28, 34, 40, 46.
October 15, 1912—1 gm. sulphate of potash No. 4563.

October 15, 1913—1 gm. sulphate of potash No. 4563.

Manure additions to pots 5, 11, 17, 23, 29, 36, 41, worked in to the depth of 3 inches.

October 15, 1910—30 grams excrement No. 3223.
October 15, 1911—30 grams excrement No. 4561.
October 15, 1912—30 grams excrement No. 3258.
October 15, 1913—30 grams excrement No. 3258.

Manure additions to pots 6, 12, 18, 24, 30, 36, 42, 48.

March 15, 1911—30 grams excrement No. 3223.
March 15, 1912—30 grams excrement No. 3258.
March 15, 1913—30 grams excrement No. 3258.

Nitrate additions:

March 15 and November 15, 1912—Added 1 gm. nitrate of soda No. 13967 to 2, 8, 14, 20; added 2 gm. to 26, 32, 38, 44.

DESCRIPTION OF SOILS.

The soils and subsoils used are described as follows::

2377—Norfolk sand; gray sandy soil, surface; Jacksonville; cultivated 15 years; has been idle 6 years.

2378—Orangeburg fine sandy loam; red sandy soil; surface; on C. D. Jarrett's farm near Dialville; cultivated since 1855.

3333—Houston loam, 0-10″; J. N. Worthy's farm, 4½ miles from Waco; good upland, rolling prairie; produces 25 to 30 bushels corn and ¼ to ¾ bales cotton per acre; light brown sandy soil; suffers from drought; known as mesquite and post oak land; cotton and corn are the principal crops; cultivated since 1882; no fertilizer used; no green crops plowed under, and no manure used.

3334—Subsoil to 3333, 10-22″; dark brown loam.

3335—Houston black clay, 0-12″; black clay; sticky when wet; Mrs. Ellis Blake, Waco; known as "black waxy land"; very good soil; produces ½ bale cotton and 35 bushels corn; cotton and corn chiefly grown; no fertilizer used; soil packs, dries into clods; does not wash, and dirt does not wash onto it; cultivated 30 to 40 years; no green crops or manure ever plowed under.

3336—Subsoil to 3335, 12-24″; black clay.

3341—Yazoo clay, 0-12″; 6 miles east of Waco; farm of Dr. Sanderson; black clay; fertile bottom land, subject to overflow; produces ½ bale cotton, 40 to 50 bushels oats, 45 bushels corn; cotton, corn and oats chiefly grown; no fertilizer used; sticky in wet seasons; works well in dry; does not pack or crack; crumbles on drying; does not wash; cultivated 50 years; no green crops or manure plowed under.

3342—Subsoil to 3341, 12-24″.

3337—Miller fine sandy loam, 0-12″; Mrs. Ellis Blake, Waco; light brown sandy soil; behaves well in wet and dry seasons; good soil; level; produces 30 to 35 bushels corn and ¼ to 1 bale cotton; cotton, corn, fruit and vegetables are grown; no fertilizer used; soil crumbles and does not pack, crack or wash; nor does dirt wash onto it; cultivated 30 to 40 years; no green crops or manure plowed under.

3338—Subsoil to 3337, 12-24″; yellow clay.

3343—Crawford clay, depth 0-7″; 6 miles east of Waco; farm of Dr. Sanderson; rolling, dark brown clay; poor yields except in wet seasons;

behaves poorly when dry; grain chiefly grown; 15 bushels corn and 25 bushels oats per acre; no fertilizer used; does not crack, pack or run together; dirt does not wash onto it; does not wash; has not been cultivated much; no manure used.

3344—Subsoil to 3343, 7-14″; black clay.

3631—Lufkin fine sandy loam, 0-6″; moderate upland; 1½ miles southwest of Giddings; produces 1200 pounds seed cotton, 45 bushels corn; well drained; moist in dry seasons; does not wash; crumbles; commercial fertilizer and manure tripled the yield; mellow in wet seasons; does not crack on drying; cultivated 25 years; 8 tons manure applied per acre.

3632—Subsoil to 3631, 6-12″.

Composition of Soils.—The chemical composition of the soils is given in Table No. 2 following:

TABLE NO. 2.

Composition of Soils Used in Percolation Work.

	Norfolk sand.	Orangeburg fine sandy loam.	Houston loam.		Houston black clay.		Yazoo clay.		Miller fine sandy loam.		Crawford clay.		Lufkin fine sandy loam.	
	Surface 2377	Subsoil 2378	Surface 3333	Subsoil 3334	Surface 3335	Subsoil 3336	Surface 3341	Subsoil 3342	Surface 3337	Subsoil 3338	Surface 3343	Subsoil 3344	Surface 3631	Subsoil 3632
Percent.														
Phosphoric acid	....	.02	.02	.012	.11	.093	.254	.249	.05	.039	.21	.137	.035	.045
Nitrogen	.03	.043	.034	.040	.119	.079	.149	.152	.05	.035	.151	.098	.056	.063
Potash	.11	.12	.21	.19	.79	.78	.70	1.04	.202	.28	.84	.77	.185	.39
Lime	.09	.11	.17	.195	3.30	4.40	2.86	2.57	.15	.15	1.12	1.29	.59	.53
Magnesia	.09	.13	.17	.155	1.12	1.05	.76	.81	.18	.285	.54	.60	.16	.43
Alumina and oxide of iron	1.21	4.16	2.73	3.59	11.67	11.85	8.23	9.14	2.51	3.84	8.50	10.82	3.09	11.64
Insoluble and soluble silica	97.22	93.69	94.84	92.68	69.78	67.67	75.28	73.65	94.87	93.20	79.83	76.79	91.93	76.22
Loss on ignition	....	....	1.49	1.99	8.25	8.17	....	....	....	....	5.53	5.67	....	....
Moisture	....	....	.54	1.09	4.60	5.21	3.24	4.25	....	.87	3.27	3.78	....	....
Parts Per Million.														
Active phosphoric acid	30.	8.	21.	10.	379.	259.	1116.	649.	122.	90.	414.	462.	94.	10.
Active potash	69.	153.	155.	113.	447.	288.	997.	849.	309.	240.	568.	461.	250.	310.
Acidity	0	0	0	0	0	0	0	0	0	0	0	0	0	0

RAINFALL.

The rainfall by months and by quarters is shown in Tables Nos. 3 and 4.

On December 4, 1913, there was a rainfall of 7.54 inches, following a steady rain of 1.39 inches the previous day. This greatly exceeded the capacity of the apparatus, as the cans overflowed at the top, and the percolating bottles were also full. For this reason, December, 1913, is excluded from the discussions in this Bulletin.

TABLE NO. 3.

Rainfall in Inches, 1911.

Days of Month.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
1			.02	.75			.33					
2	Trace				.98		.03		.07			
3	Trace			1.22	.07				.08		.01	
4				.44			.02		.01			
5												
6							1.14					.60
7							.09			.03	.45	.06
8		.19		1.42			.82				1.11	.02
9		.11		.03							.01	
10		.30						.20			.02	1.88
11		.20						.08		.16		.01
12					1.29					1.83	.01	
13		.09					.11			.53		
14		.02	.01				.01	1.25				.75
15		Trace	.09	.02			.17					.58
16				.05			.05			.16		
17	.03	.06		.50			.16				.16	
18			.41	.05			2.74	.06				
19		2.33	.35			.14						1.15
20				.04	.03							.24
21					.31	.20			.03	.28		
22			.25	1.26		.04			.03	.01		.12
23			.36	.03					.41		.07	.20
24	.18		1.53					.10	.24			.02
25	.05		.01	.13				1.78				.20
26				.92	.01							.47
27	.05	Trace						.12			.03	
28		.20			.01			.05				
29									.75	.06		.74
30				.22					.02	.47		.21
31										.02		
Totals....	0.31	3.50	3.03	7.08	2.70	.38	5.67	3.64	1.61	3.55	1.87	7.25

Rainfall in Inches, 1912.

1				.10		.37			.15			Trace
2			.02		.47	.27	.19					.02
3			.02		Trace	.03		.02	.09			1.29
4			.01		.89							.30
5			1.60		.01	.34						.10
6	.04			Trace	.42	.08		.01				
7	.01		.02	1.49								
8	.02		.05	.10								.04
9			Trace	.15								.09
10				.03	.06							.24
11	.61		.23									1.01
12	.05			.10								.35
13		1.07										.01
14			.43									
15					.27					.13		Tracc
16				Trace				.26	.26	.76		.01
17						.06	.84		.05	.55		Trace
18						.82	.02		.48	.08		
19						.10	1.85					

TABLE NO. 3—Continued.

Rainfall in Inches, 1912.

Days of Month.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
20	.....	.01	.....	.04	.....	.04	.....	.....	.....	.....	.....	.19
21	.....	.....	.09	Trace	.....	.....	.....	.....	.11	.....	.01	.72
22	.06	.....	2.28	.....	.....	.....	.08	.01	.....	.07	.73	.26
23	.06	.11	.85	.....	.....	.....	.....	.....	.....	.....	Trace	.44
24	.....	1.33	.....	.....	.....	.....	.....	.16	.....	.04	.....	.....
25	.....	.01	.....	Trace	.....	.....	.....	.01	.....	.....	.12	.....
26	.....	.....	.....	Trace	.....	.....	.....	.....	.....	.....	Trace	.....
27	.02	.....	Trace	.....	.....	.....	.....	.....	.....	.....	.05	.....
28	.05	.....	.92	.10	.....	.10	.....	.....	.....	.....	.....	.....
29	.....	.....	.....	.....	2.00	.....	.....	.....	.....	.....	.....	.26
30	.....	.....	.....	.....	.....	.....	.....	.....	.....	Trace	.....	.....
31	.....	.....	.06	.....	.....	.....	.....	.....	.....	.01	.01	.....
Totals	.92	2.53	6.58	2.11	4.12	2.21	2.98	.21	1.14	1.64	.92	5.33

Rainfall in Inches, 1913.

1	.....	.00	.....	.....	.....	.....	.....	Trace	.....	1.13	.....	Trace
2	.....	.08	.....	.....	.....	.....	.....	.....	.04	1.24	.....	.20
3	.....	.01	.....	.85	.15	.....	.....	.....	.02	.04	.....	1.39
4	.....	.....	.....	Trace	.08	.....	.....	.....	Trace	.45	.07	7.54
5	.....	.....	.....	.....	.10	.....	.....	.....	.....	.02	1.22	.75
6	Trace	.....	.....	.....	.....	.....	.....	.....	.....	.....	.03	Trace
7	.07	.49	.02	.....	.....	.....	.....	.....	.28	Trace	.02	.....
8	.....	.20	.02	.05	.....	.....	.....	.....	.....	.....	.....	.....
9	.....	Trace	1.73	.73	.....	.22	.....	.....	.46	.....	.....	.....
10	.16	1.62	.04	Trace	.....	.04	.01	Trace	.01	.....	.....	.03
11	.54	.15	.....	.....	.....	.01	.....	.01	Trace	.....	.....	.....
12	.01	.02	1.11	.....	.....	.....	.....	.01	Trace	.....	.....	.01
13	.....	Trace	.03	.....	.....	.....	.....	.....	.31	.....	.....	.24
14	.....	.....	.....	.....	.....	.....	.....	.....	.04	.....	.....	.01
15	.....	.....	.....	.....	.....	.02	.....	.....	.02	Trace	.....	.....
16	Trace	.....	.....	.....	1.00	.04	.....	.....	.....	.12	.....	.09
17	.01	.....	.....	.....	.....	.01	.....	.06	.08	1.03	.....	.66
18	.01	.....	.....	.....	.....	.07	.....	.07	.....	.05	.01	Trace
19	Trace	.....	.....	.....	.....	.....	.....	.....	.....	.01	Trace	.....
20	.02	.....	.07	.....	.48	.....	.....	.....	.....	.....	.07	.....
21	.03	.06	.17	.....	Trace	.....	.....	.....	.....	.....	.16	.....
22	.50	Trace	.....	.....	.63	.....	.....	.....	.....	.09	.01	.30
23	.07	.....	Trace	1.34	.....	.....	.....	.....	.....	.24	.86	.....
24	Trace	.....	.....	.01	.....	.07	.....	.....	.....	.....	.35	.53
25	.....	.....	.04	.....	.....	.....	.01	.....	.30	.....	.....	.....
26	.61	.....	.....	.....	.....	.....	.....	.....	.64	.01	.....	.....
27	.95	1.00	.....	.....	.....	.02	.....	.....	.21	.....	.85	.79
28	.....	.....	.....	.....	.....	.58	.....	.....	.....	.....	.11	.11
29	.....	.....	.....	.....	.....	.44	.....	.....	.....	.....	.94	.01
30	.....	.....	.....	.....	.....	.01	.....	.73	.74	.....	.04	.....
31	.....	.....	.....	.....	.....	.....	.04	.....	.....	.....	.....	.....
Totals	2.98	3.63	3.23	2.98	2.44	1.53	.06	.88	3.15	4.43	4.74	12.66

TABLE NO. 4.

Rainfall in Inches, College Station, Texas—1911, 1912 and 1913.

	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Total.
1911	0..31	3..50	3..05	7..08	2..70	0..38	5..67	2..64	1..61	3..55	1..87	7..25	39..61
1912	0..92	2..53	6..58	2..11	4..12	2..21	2..98	0..21	1..14	1..64	0..92	5..33	30..69
1913	2..98	3..63	3..23	2..98	2..44	1..53	0..06	0..88	3..15	4..43	4..74	12..66	42..71
1911	6..86			10..16			9..92			12..67			
1912	10..03			8..44			4..33			7..89			
1913	9..48			6..95			4..09			21..83			

THE PERCOLATING WATER.

The following table—Table No. 5—shows the quantity of water which percolated from the various pots, by months, during the calendar years 1911, 1912 and 1913. The symbols after the names of the soils refer to the treatment described on page 10.

TABLE NO. 5.

Water Percolated in Inches, 1911.

Pot No.		January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Total.
1	Norfolk sand—O″	......	.34	.81	1.66	.15	......	.20	......	......	......	.01	2.55	15.72
2	Norfolk sand—O 2″	......	1.61	1.63	4.03	1.16	......	1.89	......	......	.80	.77	5.05	16.94
3	Norfolk sand—O 3″	......	1.89	1.41	4.48	1.27	......	1.70	......	......	.11	.04	3.07	13.97
4	Norfolk sand—O-K_2SO_4	......	.76	.18	2.87	.58	......	.23	......	......	......	.31	4.38	9.31
5	Norfolk sand–O-manure, October	......	.95	.65	2.98	.53	......	.31	......	......	.03	.99	4.98	11.42
6	Norfolk sand—O-manure, March	......	.53	.45	3.61	1.02	......	.84	......	......	.98	1.03	5.13	13.59
7	Orangeburg fine sandy loam—O″	......	.65	.09	3.11	.59	......	.04	......	......	.01	.01	2.95	7.45
8	Orangeburg fine sandy loam—O 2″	......	1.34	1.07	3.32	.90	......	.77	......	......	.12	.27	5.43	13.22
9	Orangeburg fine sandy loam—O 3″	......	1.50	1.03	3.55	.91	......	.62	......	......	.04	.46	5.15	13.26
10	Orangeburg fine sandy loam—OMK_2SO_4	......	.54	.11	3.15	.57	......	.03	......	......	.01	.01	3.91	8.33
11	Orangeburg fine sandy loam—O-manure, October	......	1.35	.81	3.97	.96	......	......	......	......	......	.32	4.98	12.39
12	Orangeburg fine sandy loam—O-manure, March	......	.51	.21	3.39	.54	......	.05	......	......	.62	.01	3.61	8.94
13	Houston loam—O″	......	1.42	1.06	3.63	1.31	......	1.50	.24	......	1.04	.81	5.06	16.07
14	Houston loam—O 2″	......	1.16	1.18	3.30	1.30	......	1.03	.27	......	.99	.61	5.23	15.07
15	Houston loam—O 3″	......	1.65	1.40	2.87	1.55	......	1.79	.44	......	1.07	.76	5.07	16.60
16	Houston loam—O-K_2SO_4	......	1.16	1.00	3.42	1.02	......	1.27	.24	......	.99	.81	4.93	14.84
17	Houston laom—O-manure, October	......	1.92	1.36	4.14	1.26	......	1.57	.40	......	1.32	1.28	5.55	18.80
18	Houston loam—O-manure, March	......	1.45	1.12	3.53	.97	......	1.65	.32	......	1.14	.81	5.12	16.11
19	Houston black clay—O″	......	1.94	1.54	3.46	1.26	......	1.72	.44	......	1.31	1.02	5.23	17.92
20	Houston black clay—O 2″	......	1.74	1.57	4.27	1.36	......	1.85	.38	......	1.24	.95	5.16	18.52
21	Houston black clay—O 3″	......	1.95	1.57	4.58	1.41	......	2.01	.38	......	1.28	.89	5.06	19.13
22	Houston black clay—O-K_2SO_4	......	.28	.55	1.13	.19	......	.95	......	......	.09	.03	1.47	4.69
23	Houston black clay—Omanure, October	......	1.91	1.54	3.99	1.29	......	1.55	.40	......	1.43	1.09	1.51	14.71
24	Houston black clay—O-manure, March	......	.97	1.27	2.03	.41	......	1.66	.38	......	1.27	.68	4.02	12.69
25	Yazoo clay—O″	......	1.23	1.20	3.10	.93	......	1.05	.26	......	1.10	.72	4.77	14.36
26	Yazoo clay—O 2″	......	1.69	1.40	3.90	1.10	......	.09	......	......	.06	.58	5.09	13.91
27	Yazoo clay—O 3″	......	1.75	1.52	3.92	1.31	......	1.62	......	.29	1.01	.85	4.93	17.20
28	Yazoo clay—O-KrSOr.	......	1.25	1.04	3.11	.83	......	1.27	.20	......	.92	.73	4.91	14.26
29	Yazoo clay—O-manure, October	......	1.30	1.21	3.23	.98	......	1.39	.28	......	1.06	.91	4.81	15.17
30	Yazoo clay—O-manure, March	......	1.43	1.31	3.47	.98	......	1.31	.30	......	.89	.85	4.71	15.25
31	Miller fine sandy loam—O″	......	.53	.35	3.92	.54	......	.54	......	......	.19	.15	4.53	10.75
32	Miller fine sandy loam—O 2″	......	.85	.59	2.66	.71	......	1.11	......	......	.40	.19	4.41	10.92
33	Miller fine sandy loam—O 3″	......	1.13	.85	3.08	.85	......	1.30	......	......	.45	.25	4.94	12.85
34	Miller fine sandy loam—O-K_2SO_4	......	.42	.12	2.68	.48	......	.18	......	......	.08	.04	3.93	7.93
35	Miller fine sandy loam—O-manure, October	......	.45	.35	2.73	.55	......	.78	......	......	.25	.81	4.63	10.55
36	Miller fine sandy loam—O-manure, March	......	.11	.03	.35	.04	......	.13	......	......	.07	.02	.44	1.19
37	Crawford clay—O″	......	1.91	1.69	3.96	1.45	......	2.24	.63	......	1.43	.99	5.22	19.52
38	Crawford clay—O 2″	......	2.33	1.65	2.92	1.30	......	1.94	.40	......	1.17	.73	4.61	17.05

TABLE NO. 5—Continued.

Water Percolated in Inches, 1911.

Pot No.		January.	February.	Mareh.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Totals.
39	Crawford clay—O 3″......	......	1.93	1.68	4.48	1.30	......	2.14	.43	......	1.19	.92	5.48	19.55
40	Crawford clay—O-K_2SO_4......	......	1.65	1.54	3.90	1.22	......	1.88	.47	......	1.25	.95	4.78	17.64
41	Crawford clay—O-manure, October......	......	1.69	1.51	4.01	1.36	......	1.95	.43	......	1.38	1.04	5.33	18.70
42	Crawford clay—O-manure, March......	......	1.65	1.45	3.83	1.23	......	1.71	.46	......	1.20	1.03	4.73	17.29
43	Lufkin sandy loam—O″......	......	.81	.12	3.26	.93	......	.70	......	......	.57	.38	3.97	10.74
44	Lufkin sandy loam—O 2″......	......	1.23	.71	3.56	.82	......	1.08	......	.08	.67	.34	4.56	13.05
45	Lufkin sandy loam—O 3″......	......	1.09	.46	3.92	.93	......	1.11	......	.11	.63	.34	5.03	13.62
46	Lufkin sandy loam—O-K_2SO_4......	......	1.04	.62	2.76	.81	......	.83	......	......	.56	.36	4.15	11.13
47	Lufkin sandy loam—O-manure, October......	......	.95	.67	3.74	.72	......	1.01	......	......	.58	.76	4.77	13.20
48	Lufkin sandy loam—O-manure, March......	......	1.57	1.55	4.09	.63	......	.74	......	......	.44	.29	4.36	13.67

TABLE NO. 5—Continued.

Inches of Water Removed from Percolation Pots, 1912.

Pot No.		January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Totals.
1	Norfolk sand—O″	.03	.23	2.60	1.40	.01	......	......	......	......	......	.02	.23	4.52
2	Norfolk sand—O 2″	.11	1.05	3.69	1.49	.67	1.03	.26	......	......	......	.01	2.81	11.12
3	Norfolk sand—O 3″	.08	.27	3.11	.66	.40	.77	.27	......	......	......	.04	.04	5.64
4	Norfolk sand—O-K_2SO_4	.11	.35	3.70	1.43	.01	.08	.01	......	......	......	.01	1.35	7.05
5	Norfolk sand—O-manure, October	.13	.50	3.11	1.80	.01	.11	.03	......	......	......	.06	2.18	7.93
6	Norfolk sand—O-manure, March	.14	.50	3.59	1.70	.05	.40	......	......	......	......	......	.196	8.34
7	Orangeburg fine sandy loam—O″	.04	.09	3.51	1.62	.01	......	.01	......	......	......	.05	.99	6.32
8	Orangeburg fine sandy loam—O 2″	.13	.61	3.94	1.97	.31	.79	......	......	......	......	......	1.76	9.51
9	Orangeburg fine sandy loam—O 3″	.07	.67	3.90	2.09	.21	.54	......	......	......	......	.03	2.14	9.65
10	Orangeburg fine sandy loam—O-K_2SO_4	.05	.04	3.60	1.80	......	......	......	......	......	......	......	.42	5.91
11	Orangeburg fine sandy loam—O-manure, October	.13	.86	3.52	1.89	.01	.26	.03	......	......	......	.01	1.23	7.94
12	Orangeburg fine sandy loam—O-manure, March	.07	.18	3.78	1.61	.02	.01	.01	......	......	......	......	.82	6.50
13	Houston loam—O″	.20	.128	3.31	2.19	.42	1.11	.03	......	......	......	.03	2.99	11.56
14	Houston loam—O 2″	.18	.82	2.30	2.43	.56	1.21	.21	......	......	......	.07	2.54	10.32
15	Houston loam—O 3″	.35	.79	2.08	2.52	.43	1.04	.34	......	......	......	.07	3.14	10.76
16	Houston loam—O-K_2SO_4	.12	.75	3.37	1.93	.23	.97	.16	......	......	......	.05	2.91	10.49
17	Houston loam—O-manure, October	.16	1.21	3.88	2.15	.49	1.31	.06	......	......	......	.09	3.43	12.78
18	Houston loam—O-manure, March	.11	.76	3.41	1.72	.35	1.14	.19	......	......	......	.01	2.81	10.50
19	Houston black clay—O″	.11	1.37	4.01	2.13	.52	1.17	.11	......	......	......	.02	3.33	12.77
20	Houston black clay—O 2″	.13	1.36	3.91	1.79	.55	1.15	.25	......	......	......	.01	3.05	12.20
21	Houston black clay—O 3″	.13	1.29	4.05	2.15	.55	1.12	.31	......	......	......	.06	3.10	12.76
22	Houston black clay—O-K_2SO_4	.03	.15	1.64	.42	.07	.56	.02	......	......	......	.01	.11	3.01
23	Houston black clay—O-manure, October	.14	1.42	3.91	2.10	.54	1.24	.25	......	......	......	.06	3.40	13.06
24	Houston black clay—O-manure, March	.01	.64	3.26	1.53	.33	1.08	.21	......	......	......	......	1.79	8.87
25	Yazoo clay—O″	.02	.97	3.37	1.75	.29	.79	.04	......	......	......	.01	2.74	9.98
26	Yazoo clay—O 2″	.08	.99	3.83	1.89	.46	.98	.02	......	......	......	.01	2.63	10.89
27	Yazoo clay—O 3″	.06	1.15	3.87	1.89	.38	.86	.06	......	......	......	.06	2.88	11.21
28	Yazoo clay—O-K_2SO_4	.02	.86	3.53	1.60	.33	.82	.02	......	......	......	......	2.61	9.79
29	Yazoo clay—O-manure, October	.04	1.17	3.33	1.85	.40	.97	.12	......	......	......	.03	2.80	10.71
30	Yazoo clay—O-manure, March	.04	.93	3.55	1.52	.29	.79	.02	......	......	......	.01	1.38	8.53
31	Miller fine sandy loam—O″	.10	.23	3.21	1.92	.01	.10	.03	......	......	......	.08	2.30	7.98
32	Miller fine sandy loam—O 2″	.03	.02	2.59	1.59	.22	.43	.01	......	......	......	.01	2.27	7.17
33	Miller fine sandy loam—O 3″	.03	.28	3.12	2.08	.19	.21	.01	......	......	......	.06	2.64	8.62
34	Miller fine sandy loam—O-K_2SO_4	.01	.05	3.03	1.45	.02	.03	.02	......	......	......	......	1.77	6.38
35	Miller fine sandy loam—O-manure, October	.02	.21	2.93	1.91	.01	.02	.07	......	......	......	.02	.70	5.89
36	Miller fine sandy loam—O-manure, March	......	......	.57	.21	......	.03	.02	......	......	......	......	.11	.94
37	Crawford clay—O″	.11	.89	2.53	2.08	.58	1.31	.40	......	......	......	.01	3.23	11.14
38	Crawford clay—O 2″	.04	1.36	3.67	1.80	.42	.67	.01	......	......	......	......	2.60	10.57

TABLE NO. 5—Continued.

Inches of Water Removed from Percolation Pots, 1912.

Pot No.		January.	February.	March.	Apirl.	May.	June.	July.	August.	September.	October.	November.	December.	Totals.
39	Crawford clay—O 3″...	.12	1.38	2.89	2.13	.55	.23	.36	......	......	......	.07	3.15	10.88
40	Crawford clay—O-K_2SO_4	.04	.93	3.67	1.84	.33	.16	.11	......	......	......	.01	3.17	10.26
41	Crawford clay—O-manure, October	.13	1.46	2.53	2.21	.57	1.42	.34	......	......	......	.01	3.14	11.81
42	Crawford clay—O-manure, March	.09	1.13	2.26	1.77	.47	1.16	.26	......	......	......	......	2.95	10.09
43	Lufkin fine sandy loam—O″...	.31	.27	1.56	1.99	.15	.54	.09	......	......	......	.09	2.17	7.17
44	Lufkin fine sandy loam—O 2″...	.11	.20	1.84	2.29	.27	.51	.14	......	......	......	.01	2.50	7.87
45	Lufkin fine sandy loam—O 3″...	.19	.28	1.94	2.88	.21	.74	.11	......	......	......	.05	2.78	9 18
46	Lufkin fine sandy loam—-K_2SO_4	.12	.40	2.95	1.73	.14	.56	.02	......	......	......	......	2.31	8.23
47	Lufkin fine sandy loam—O-manure, October	.06	.22	2.31	2.92	.01	1.27	.01	......	......	......	.05	2.01	8.86
48	Lufkin fine sandy loam—O-manure, March	.02	.21	2.81	1.87	.02	.41	......	......	......	......	......	.70	6.04

TABLE NO. 5—Continued.

Inches of Water Percolated from Percolation Pots, 1913.

Pot No.		January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Totals 11 months.
1	Norfolk sand—O″	.08	.01	.12	.01	.01	.....	.....	.....	.....	.03	.02	.....	.28
2	Norfolk sand—O 2″	1.58	1.69	2.06	.42	.17	.....	.....	.....	.....	2.13	.88	.....	8.93
3	Norfolk sand—O 3″	.04	.05	.08	.03	.....	.01	.....	.....	.....	.05	.05	.....	.31
4	Norfolk sand—O-K_2SO_4	1.53	1.68	1.72	.02	.02	.....	.....	.....	.....	.77	.03	.....	5.77
5	Norfolk sand—O-manure, October	1.43	1.73	2.29	.37	.22	.02	.....	.....	.....	1.11	.04	.....	7.21
6	Norfolk sand—O-manure, March	1.33	1.42	2.11	1.00	.52	.01	.....	.....	.....	2.54	1.43	.....	10.36
7	Orangeburg fine sandy loam—O″	1.39	1.24	1.75	.03	.01	.02	.....	.....	.....	.38	.03	.....	4.85
8	Orangeburg fine sandy loam—O 2″	1.66	1.67	1.77	.03	.01	.01	.....	.....	.....	1.14	.19	.....	6.48
9	Orangeburg fine sandy loam—O 3″	1.68	1.82	2.00	.....	.....	.....	.....	.....	.....	1.72	.78	.....	8.00
10	Orangeburg fine sandy loam—O-K_2SO_4	1.09	1.56	1.39	.02	.....	.01	.....	.....	.....	.20	.01	.....	4.28
11	Orangeburg fine sandy loam—O-manure, October	1.40	1.75	2.51	.53	.17	.01	.....	.....	.....	1.22	.09	.....	7.68
12	Orangeburg fine sandy loam—O-manure, March	1.38	1.65	1.80	.42	.15	.....	.....	.....	.....	1.39	1.13	.....	7.92
13	Houston loam—O″	1.43	1.94	2.28	.46	.16	.02	.....	.....	.....	2.48	.76	.....	7.53
14	Houston loam—O 2″	1.25	2.11	1.90	.63	.17	.01	.....	.....	.....	2.65	.89	.....	9.61
15	Houston loam—O 3″	.96	1.94	1.70	.49	.15	.04	.....	.....	.....	2.85	.96	.....	9.09
16	Houston loam—O-K_2SO_4	1.18	1.95	1.95	.57	.14	.05	.....	.....	.....	2.36	.68	.....	8.88
17	Houston loam—O-manure, October	1.53	2.05	2.65	.90	.37	.....	.....	.....	.....	3.01	1.16	.....	11.67
18	Houston loam—O-manure, March	1.32	1.82	2.08	1.02	.16	.04	.....	.....	.....	2.67	1.22	.....	10.33
19	Houston black clay—O″	1.60	1.99	2.69	.79	.31	.05	.....	.....	.....	2.83	1.03	.....	11.29
20	Houston black clay—O 2″	1.67	2.01	2.59	.76	.25	.03	.....	.....	.....	2.59	.90	.....	10.80
21	Houston black clay—O 3″	2.72	2.06	2.86	.79	.25	.02	.....	.....	.....	2.30	1.26	.....	12.26
22	Houston black clay—O-K_2SO_4	.06	.25	.04	.14	.03	.01	.....	.....	.....	.06	.05	.....	.64
23	Houston black clay—O-manure, October	1.78	2.04	2.76	.77	.25	.03	.....	.....	.....	2.83	1.10	.....	11.56
24	Houston black clay—O-manure, March	.93	1.37	1.43	.22	.01	.....	.....	.....	.....	.14	.06	.....	4.16
25	Yazoo clay—O″	1.42	1.82	2.26	.37	.04	.02	.....	.....	.....	2.70	.92	.....	9.55
26	Yazoo clay—O 2″	1.56	1.86	2.38	.85	.18	.02	.....	.....	.....	1.45	.01	.....	8.31
27	Yazoo clay—O 3″	1.68	2.05	2.71	.69	.19	.03	.....	.....	.....	2.54	1.14	.....	11.03
28	Yazoo clay—O-K_2SO_4	1.35	1.69	2.17	.22	.08	.02	.....	.....	.....	2.75	.80	.....	9.08
29	Yazoo clay—O-manure, October	1.47	1.88	2.44	.65	.04	.02	.....	.....	.....	2.81	1.04	.....	10.35
30	Yazoo clay—O-manure, March	1.06	1.22	1.66	.68	.02	.02	.....	.....	.....	.87	.28	.....	5.81
....	Miller fine sandy loam—O″	1.39	1.86	1.85	.04	.02	.01	.....	.....	.....	.62	.05	.....	5.84
32	Miller fine sandy loam—O 2″	1.48	1.63	1.58	.27	.04	.01	.....	.....	.....	2.08	.65	.....	7.74
33	Miller fine sandy loam—O 3″	1.44	1.83	1.90	.13	.....	.....	.....	.....	.....	2.30	.67	.....	8.27
34	Miller fine sandy loam—O-K_2SO_4	.89	1.52	1.24	.03	.01	.02	.....	.....	.....	1.22	.01	.....	4.94
35	Miller fine sandy loam—O-manure, October	.79	.57	.28	.....	.....	.....	.....	.....	.....	.36	.....	.....	2.00
36	Miller fine sandy loam—O-manure, March	.04	.01	.03	.....	.....	.....	.....	.....	.....	1.14	.....	.....	1.22
37	Crawford clay—O″	1.49	1.97	2.56	.80	.02	.....	.....	.....	.....	2.90	1.18	.....	10.92
38	Crawford clay—O 2″	1.44	1.87	2.41	.53	.04	.01	.....	.....	.....	1.77	.18	.....	8.25

TABLE NO. 3—Continued.

Inches of Water Percolated from Percolation Pots, 1913.

Pot No.		January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Totals.
39	Crawford clay—O 3″	1.62	2.03	2.72	.88	.33	.03	......	......	......	2.69	1.15	......	11.45
40	Crawford clay—O-K_2SO_4	1.56	1.86	2.40	.52	.16	......	......	......	......	3.11	1.05	......	10.66
41	Crawford clay—O-manure, October	1.34	1.90	2.60	.63	.02	.02	......	......	......	1.99	.84	......	9.34
42	Crawford clay—O-manure, March	1.46	1.74	2.20	.71	.29	.03	......	......	......	2.84	1.04	......	10.31
43	Lufkin fine sandy loam—O″	.62	1.99	1.01	.04	......	.01	......	......	......	.81	.21	......	4.69
44	Lufkin fine sandy loam—O 2″	.53	1.32	.84	.06	.02	......	......	......	......	1.92	.32	......	5.01
45	Lufkin fine sandy loam—O 3″	.78	1.97	1.75	.12	.01	.02	......	......	......	2.41	.72	......	7.78
46	Lufkin fine sandy loam—O-K_2SO_4	1.07	1.67	1.55	.09	.03	......	......	......	......	1.67	.28	......	6.36
47	Lufkin fine sandy loam—O-manure, October	1.06	1.90	1.70	.01	.01	......	......	......	......	1.70	.28	......	6.66
48	Lufkin fine sandy loam—O-manure, March	.40	.09	.32	.05	.01	......	......	......	......	.64	.02	......	1.53

EFFECT OF SOIL TYPE ON PERCOLATION AND EVAPORATION.

The soils may be divided into two groups with respect to the quantity of water which passed through them when uncultivated: (a) Those whose average annual percolation is less than 10 inches, and (b) those whose average annual percolation is over 10 inches.

Table No. 6 contains a summary of percolation from the uncultivated soils by groups.

TABLE NO. 6.

Total Percolation in Inches from Uncultivated Soils.

Pot No.	Name.	1911.	1912.	1913 (December excluded).	Average.	Evaporation.
1	Norfolk sand	5.72	4.52	.28	3.51	....
7	Orangeburg fine sandy loam	7.45	6.32	4.85	6.21	....
31	Miller fine sandy loam	10.75	7.98	5.84	8.19	....
43	Lufkin sandy loam	10.74	7.17	4.69	7.53	....
	Average	8.67	6.50	3.92	6.36	27.09
13	Houston loam	16.07	11.56	7.53	11.72	....
19	Houston black clay	17.92	12.77	11.29	13.99	....
25	Yazoo clay	14.36	9.98	9.55	11.30	....
37	Crawford clay	19.52	11.14	10.92	13.86	....
	Average	16.97	11.36	9.82	12.72	20.73
	Average rainfall, December, 1913, excluded	....	....	....	....	33.45

The average percolation from the clays is double the quantity from the sands or sandy loams. Conversely, the sands and sandy loams lost much greater quantities of water by evaporation than did the clays. The above refers to the uncultivated soils.

The average annual rainfall for the three years (December, 1913, excluded) is 33.45 inches. According to the table previously cited, we may expect a loss by run-off of about 8 inches on gentle slopes and 17 inches on steep slopes. As a portion of the Texas rainfall comes in heavy rains of short duration, we may consider a loss of 8 inches by run-off as a moderate estimate.

The run-off of 8 inches is, however, less than the amount of percolation from the sands and sandy loams. In other words, there would be no percolation if we deduct this quantity of run-off.

The percolation from the Houston loam and the clays exceeds the estimated run-off by 6 inches.

The quantity of percolating water may be assumed to represent that at the disposal of the crops. This is not strictly true, for the shade and presence of the growing crop decreases evaporation from the soil; while, on the other hand, a large portion of the percolation comes during the winter season when there is no crop on the ground. Hence, this water can be of advantage only if it remains in the soil, instead of percolating. These facts must be duly considered, and also that the uncultivated soil only is being considered. The following is the crop yield for which the average amounts of percolating water given above would suffice, based upon the *assumption* that the water required is the quantity given on page 6 of this Bulletin.

Water for Crop Production.

	Sands and loams.	Clays.
No run-off assumed—		
Cotton	510 lbs. lint	1,016 lbs. lint
Corn	38 bu.	76 bu.
Oats	57 bu.	114 bu.
Alfalfa or hay	4,860 lbs.	9,650 lbs.
Run-off of eight inches assumed—		
Cotton	....	376 lbs.
Corn	....	28 bu.
Oats	....	43 bu.
Alfalfa or hay	....	3,570 lbs.

It must be remembered that these are uncultivated soils, and that, when cultivation is given, much larger quantities of water are retained by the cultivated soils.

The rainfall, percolation and evaporation at Rothamsted, England, for an average of twenty years, are given below, together with similar results of the Texas experiments:

	Rainfall.	Percolation.	Evaporation.
Rothamsted	28.5	15.0	13.5
Texas, light soils	35.15	7.67	27.09
Texas, heavy soils	35.15	14.15	20.73

The Rothamsted soil is a heavy clay, and is not cultivated. Evaporation at Rothamsted is much less than in Texas, but the percolation through the heavy soils of Texas is remarkably close to that through the one at Rothamsted.

Evaporation and Percolation by Quarters.—The following table, No. 7, shows the evaporation and percolation from the uncultivated soil types by quarters. The results given are the average of the three years.

TABLE NO. 7.

Percolation by Quarters.

	Jan., Feb., Mar.	April. May, June.	July, Aug., Sept.	Oct., Nov., Dec.
Norfolk sand	1.41	1.08	0.07	0.95
Orangeburg fine sandy loam	2.92	1.80	0.02	1.47
Miller fine sandy loam	3.17	2.19	0.19	2.64
Lufkin fine sandy loam	2.23	2.31	0.26	2.73
Average	2.43	1.85	0.14	1.95
Houston loam	4.64	3.43	0.59	4.39
Houston black clay	5.08	3.56	0.76	4.96
Yazoo clay	4.10	2.43	0.45	4.32
Crawford clay	4.05	3.40	1.09	4.99
Average	4.47	3.21	0.72	4.67

TABLE A.

Group 1, Sands.

	Precipitation.	Percolation.	Evaporation.	Per cent evaporated.
January, February, March..........	8.91	2.43	6.48	72
April, May, June..................	8.52	1.85	6.67	78
July, August, September...........	6.11	0.14	5.97	98
October, November, December.....	9.91	1.95	7.96	80

Group 2, Clays.

	Precipitation.	Percolation.	Evaporation.	Per cent evaporated.
January, February, March..........	8.91	4.47	4.44	50
April, May, June..................	8.52	3.21	5.31	62
July, August, September...........	6.11	0.72	5.39	88
October, November, December.....	9.91	4.67	5.24	53

If we assume that all the water precipitated during the quarter either evaporates or percolates during that quarter—an assumption which is not true, as some of the water may be stored up, or some stored up may be evaporated—the results would be as given in Table A.

Attention should be directed to the high percentages of water evaporated, especially during the summer months. This emphasizes the need for storing water in the soil.

EFFECT OF CULTIVATION UPON EVAPORATION AND PERCOLATION.

Table No. 8 shows the annual percolation from the soils, uncultivated, and cultivated, to the depth of two or three inches. The cultivation was made every week throughout the year, or, in case a rain intervened, as soon as the soil became in condition suitable for cultivation.

The soils are divided into the same two groups as in the previous discussion. The average gain in percolation, due to the cultivation to a depth of 2 inches was, with the first group, 3.52 inches, and in the second group, zero. Cultivation to a depth of two inches caused a gain in percolation from all the soils in Group 1.

TABLE NO. 8.

Percolation in Inches from Soils.

	No cultivation.	Cultivated.	
		2 inches.	3 inches.
Norfolk sand—			
1911..............................	5.72	16.94	13.97
1912..............................	4.52	11.12	5.64
1913..............................	0.28	8.93	0.31
Average...........................	3.51	12.33	6.64
Orangeburg fine sandy loam—			
1911..............................	7.45	13.22	13.26
1912..............................	6.32	9.51	9.65
1913..............................	4.85	6.48	8.00
Average...........................	6.21	9.74	10.30

TABLE NO. 8—Continued.

Percolation in Inches from Soils.

	No cultivation.	Cultivated.	
		2 inches.	3 inches.
Miller fine sandy loam—			
1911	10.75	10.93	12.85
1912	7.98	7.17	8.62
1913	5.84	7.74	8.27
Average	8.19	8.61	9.91
Lufkin fine sandy loam—			
1911	10.74	13.05	13.62
1912	7.87	9.18	8.23
1913	4.69	5.01	7.78
Average	7.77	9.08	9.88
Group average	6.42	9.94	9.18
Houston loam—			
1911	16.07	15.07	16.60
1912	11.56	10.32	10.76
1913	7.53	9.61	9.09
Average	11.72	11.67	12.15
Houston black clay—			
1911	17.92	18.52	19.13
1912	12.77	12.20	12.76
1913	11.29	10.80	12.26
Average	13.99	13.84	14.72
Yazoo clay—			
1911	14.30	13.91	17.20
1912	9.98	10.89	11.21
1913	9.55	8.31	11.03
Average	11.30	11.04	13.15
Crawford clay—			
1911	19.52	17.05	19.55
1912	11.14	10.57	10.88
1913	10.92	8.25	11.45
Average	11.86	11.96	13.96
Group average	12.22	12.13	13.50

On the other hand, cultivation to the depth of 2 inches did not cause a gain in percolating water with any of the soils in Group 2.

Cultivation to the depth of three inches caused a less average decrease in evaporation with the sands and loams than did the two-inch cultivation. There is a decrease with two of the soils, and an increase with the other two. Cultivation to the depth of three inches decreased evaporation on an average, from all the loam and clays of Group 2.

Water was observed to stand upon pots 14 and 15 of the Houston loam, and on pots 43, 44 and 45 of the Lufkin fine sandy loam more frequently than on other pots in the series. This is reflected in the table, by the decreased percolation from these two soils in 1912 and in 1913.

The following table shows the average evaporation from the two groups of soils:

Evaporation from Uncultivated and Cultivated Soils.

	No cultivation.	Cultivated.	
		2 inches.	3 inches.
Four sands and loams	27.03	23.51	24.27
Four loams and clays	21.23	21.32	19.95

It is evident, from the foregoing discussion, that cultivation is much more effective in decreasing evaporation from some soils than from others, and that those on which it is effective are the sands or loam soils which lose water rapidly by evaporation from the uncultivated soil. The difference, however, may be due to some other factor operating during wet periods, and not to natural evaporation differences.

The average evaporation from the clays and loam is much less, even from the uncultivated soils, than it is from the sands and loams. A three-inch cultivation may also be effective on the heavier soils, where a two-inch cultivation has little or no value.

The gain of water due to the checking of evaporation by a two-inch cultivation of the sands or loams averages 3.52 inches per year. If this saving of moisture occurred during the crop season, and could all be utilized by the crop, it would be sufficient approximately for the following production:

Cotton, pounds lint	280
Corn, bushels	21
Wheat, bushels	14
Oats, bushels	33

Table No. 9 shows the percolation by quarters from the cultivated and uncultivated soils. Table No. 10 shows the increased quantity of water percolated, due to the cultivation. The table brings out clearly the low percolation during the summer months. Part of the diminished percolation during the winter months may be due to the replacement of water evaporated during the summer.

These tables again emphasize the necessity of storing water in the soil and subsoil for use during the growing season. They also bring out the very slight effect of the cultivation of the clay group of soils, on the loss of water in percolation pots.

TABLE NO. 9.

Percolation in Inches by Quarters.

	No cultivation.	Cultivated.	
		2 inches.	3 inches.
January, February, March, 1911-1912—			
Norfolk sand	1.41	4.47	2.31
Orangeburg fine sandy loam	2.92	4.10	4.19
Miller fine sandy loam	3.17	2.92	3.53
Lufkin fine sandy loam	2.23	2.26	2.82
Average	2.43	3.44	3.21
Houston loam	4.64	3.60	3.59
Houston black clay	5.08	4.99	5.54
Yazoo clay	4.10	4.56	4.93
Crawford clay	4.05	4.92	4.79
Average	4.47	4.50	4.71
April, May, June, 1911-1912—			
Norfolk sand	1.08	2.99	2.54
Orangeburg fine sandy loam	1.80	2.45	2.43
Miller fine sandy loam	2.19	1.98	2.18
Lufkin fine sandy loam	2.31	2.51	2.94
Average	1.85	2.48	2.52

TABLE NO. 9—Continued.

Percolation in Inches by Quarters.

	No cultivation.	Cultivated.	
		2 inches.	3 inches.
Houston loam	3.43	3.20	3.06
Houston black clay	3.56	3.39	3.62
Yazoo clay	2.43	3.13	3.09
Crawford clay	3.40	2.56	3.31
Average	3.21	3.08	3.27
July, August, September, 1911-1912—			
Norfolk sand	.07	.72	.66
Orangeburg fine sandy loam	.02	.26	.21
Miller fine sandy loam	.19	.37	.44
Lufkin fine sandy loam	.26	.43	.44
Average	.14	.45	.44
Houston loam	.59	.50	.86
Houston black clay	.76	.83	.90
Yazoo clay	.45	.64	.66
Crawford clay	1.09	.78	.98
Average	.72	.54	.85
October, November, December, 1911-1912—			
Norfolk sand	.95	4.15	1.13
Orangeburg fine sandy loam	1.47	3.30	3.44
Miller fine sandy loam	2.64	3.34	3.77
Lufkin fine sandy loam	2.73	3.44	3.99
Average	1.95	3.56	3.08
Houston loam	4.39	4.33	4.41
Houston black clay	4.96	4.63	4.65
Yazoo clay	4.32	3.28	4.47
Crawford clay	4.99	3.69	4.88
Average	4.67	3.98	4.60

TABLE NO. 10.

Increase in Quantity of Water Percolated, by Quarters, Over Uncultivated Soil.

	Cultivated 2 inches.	Cultivated 3 inches.
Sand Group—		
January, February, March	1.01	0.78
April, May, June	0.63	0.67
July, August, September	0.31	0.30
October, November, December	1.61	1.13
Clay Group—		
January, February, March	.05	.24
April, May, June	.13	.06
July, August, September	.18	.13
October, November, December	.69	.07

The decreased loss in evaporation, due to the cultivation during the six crop months, is nearly an inch of water, which would be sufficient for about 80 pounds cotton, 6 bushels corn, or 9 bushels oats. The average production of cotton in Texas in 1909, according to the U. S. census, is 125 pounds cotton lint, and 14.7 bushels corn. The gain of water by cultivation would thus be two-thirds of the average cotton crop or two-fifths of the average corn crop. It might, indeed, be much more.

Table No. 11 shows the percentages evaporated, based upon the assumption that all the water which fell during the season either evaporated or percolated. This assumption is, of course, not true, but the table emphasizes the high percentage evaporation during the summer months, which are probably really higher than the figures given.

TABLE NO. 11.

Percentages Evaporated and Percolated (estimated).

	Precipitation.	Percolation 2″	Evaporation 2″	Per cent evaporated 2″. Approximate.	Per cent evaporated from uncultivated soil.
Sandy Group—					
January, February, March	8.91	3.44	5.47	61	72
April, May, June	8.52	2.48	6.02	71	78
July, August, September	6.11	0.45	5.66	93	98
October, November, December	9.91	3.56	6.35	64	80
Clay Group—					
January, February, March	8.91	4.71	4.20	47	50
April, May, June	8.52	3.27	5.25	62	62
July, August, September	6.11	0.85	5.26	86	88
October, November, December	9.91	4.60	5.31	54	53

EFFECT OF SULPHATE OF POTASH AND MANURE ON PERCOLATION.

Table No. 12 compares the percolation from the soils which received sulphate of potash, and manure, with the zero pot. None of these soils were cultivated, except to the extent necessary to work in the manure when it was applied.

Sulphate of potash caused an average increase of percolation with the sandy soils. This increase occurred with two of the four soils of the group; with the Miller fine sandy loam, there was a decided decrease. On the other hand, the sulphate of potash caused a decided decrease in percolation with the loam and clay soils, amounting on an average to 3.20 inches, and occurring with all the soils of the group. This is perhaps due to the saline material causing the surface soil to run together, decreasing the penetration of water, and causing it to remain near the surface to undergo evaporation. The Houston black clay, particularly, showed a great decrease in percolation, due to the presence of the sulphate of potash.

The quantity of sulphate of potash used in 1911 was equal to an annual application of 68 pounds potash (K_2O). In 1912, three times this quantity was added to the Norfolk sand, Orangeburg fine sandy loam, Houston loam and Houston black clay, and five times as much to the Yazoo clay, Miller fine sandy loam, Crawford clay and Lufkin fine sandy loam, but there is no evidence that the increased application caused an increased evaporation during the year 1912 over that of 1911. According to these results, application of soluble salts to the heavy soils may result in no increased loss of moisture.

The application of the manure resulted in a decreased loss of water by evaporation from the sandy soils especially. With the clay soils, the manure applied October 15 caused a decreased loss of water, while that applied March 15 increased the loss. With almost all the soils, the fall application of manure resulted in a greater saving of moisture than the spring application. Some of the pots to which manure was applied evidently had something wrong with them and did not allow the water to percolate as it should. This is particularly true of the Miller fine sandy loam, and also the Lufkin fine sandy loam.

TABLE NO. 12.

Percolation in Inches from Uncultivated Soils.

	No addition.	Sulphate of potash.	Manure, Oct. 15.	Manure, Mar. 15.
Norfolk sand—				
1911	5.72	9.31	11.42	13.59
1912	4.57	7.05	8.30	8.34
1913	0.28	5.77	7.21	10.36
Average	3.52	7.38	8.98	10.36
Orangeburg fine sandy loam—				
1911	7.45	8.33	12.39	8.94
1912	6.32	5.91	7.94	6.50
1913	4.85	4.28	7.68	7.92
Average	6.21	6.17	9.34	7.79
Miller fine sandy loam—				
1911	10.75	7.93	10.53	1.19
1912	7.98	6.38	5.89	0.94
1913	5.84	4.94	2.00	1.22
Average	8.19	6.42	6.14	1.12
Lufkin fine sandy loam—				
1911	10.74	11.13	13.20	13.67
1912	7.87	8.23	8.86	6.04
1913	4.69	6.36	6.66	1.53
Average	7.77	8.57	9.57	7.08
Average of sands and loams	6.42	7.14	8.51	6.69
Houston loam—				
1911	16.07	14.84	18.80	16.11
1912	11.56	10.49	12.78	10.50
1913	7.53	8.88	11.67	10.33
Average	11.72	11.40	14.42	12.31
Houston black clay—				
1911	17.92	4.73	14.71	12.69
1912	12.77	3.01	13.06	8.85
1913	11.29	0.64	11.56	4.16
Average	13.99	2.79	13.11	8.57
Yazoo clay—				
1911	14.36	14.26	15.17	15.25
1912	9.98	9.79	10.71	8.53
1913	9.55	9.08	10.35	5.81
Average	11.30	11.04	12.08	9.86
Crawford clay—				
1911	19.52	17.64	18.64	17.29
1912	11.14	10.26	11.81	10.09
1913	10.92	10.66	9.34	10.31
Average	13.86	12.85	13.26	12.56
Average of clays	12.72	9.52	13.22	10.83

The average saving of moisture by the manure on the sandy and loam soils is as follows:

Manure—October 15	2.09
Manure—March 15	0.27

The saving by cultivation is 3.52 inches. The saving due to the manure would suffice for the production of the following crops, if it could all be used:

	Manure, October 15.
Cotton, pounds	167
Corn, bushels	13
Wheat, bushels	8
Oats, bushels	19
Hay, pounds	1600

With the clays and heavy loams, the saving is much less.

The important effect of manure on the saving of moisture with the sands and sandy loam soils deserves especial emphasis. Manure or green crops are undoubtedly needed by these soils, not only for this purpose, but for the other favorable effects upon the condition of the soil. But it appears that an application of ten tons of manure per year on the sands and sandy loam soils may result in a saving of moisture from loss by evaporation sufficient to make more than an average crop of cotton, and nearly an average crop of corn.

PERCOLATION OF NITRATES.

The plan of the work at first included only the estimation of the nitrates from the pots not cultivated, which received no addition, and which received manure March 15 and October 15. Later, however, the plan was expanded to include the estimation of nitrates in all the percolates.

The nitrates were in each case estimated colorimetrically by the phenol-sulphuric acid method the same day that the percolates were collected.

We will discuss first the results from the work which was carried out on the original plan, and take up the other nitrate work on another page.

Table No. 13 shows the nitric nitrogen in the percolates for 1911, 1912 and 1913 in parts per million of the percolating water. This gives the concentration of nitric nitrogen in the percolate.

Table No. 14 shows the quantity of nitric nitrogen lost per pot per month, in the groups studied.

As pointed out elsewhere in this Bulletin, a heavy rain in December, 1913, exceeded both the capacity of the free space of the pots to retain on the surface, and the capacity of the bottles which received the percolates, and, for this reason, December is not included in the work for the year. As, however, the analyses are of some interest, they are recorded in the tables.

TABLE NO. 13.

Nitrates Percolated, Parts Per Million, 1911.

Pot Number.	February.		March.				April.							May.	
	18-19th.	23rd.	3rd.	21st.	24th.	27th.	3rd.	5th.	10th.	14th.	20th.	25th.	28th.	5th.	10th.
1	......	23	......	......	......	30	......	22	14	......	......	10	12	7	......
5	13	10	......	......	......	14	......	19	14	......	......	10	10	6	8
6	......	......	......	......	......	33	......	28	22	......	......	12	11	10	12
7	111	90	......	......	......	111	87	95	74	......	......	38	36	19	......
11	67	......	......	......	......	54	43	40	31	......	......	19	33	16	16
12	......	......	......	......	......	87	71	66	50	......	......	29	31	17	......
13	75	35	30	17	......	33	33	26	23	22	11	14	13	11	11
17	33	29	33	26	36	28	23	22	16	14	9	13	14	12	13
18	......	......	......	......	28	31	26	28	19	17	11	13	14	12	16
19	62	59	58	58	62	41	37	36	26	22	12	19	20	19	18
23	71	48	58	58	53	41	28	36	25	22	20	18	21	23	26
24	......	......	......	......	......	50	......	30	26	......	......	20	23	4	20
25	200	133	......	......	160	180	......	100	83	......	40	38	57	29	48
29	160	148	......	......	57	166	95	138	95	......	53	47	66	48	50
30	......	......	......	......	133	125	100	91	74	......	53	40	50	33	48
31	17	100	......	14	......	105	......	93	71	......	......	40	45	33	......
35	......	103	......	......	......	111	......	100	71	......	......	42	55	31	36
36	......	......	......	......	......	117	......	138	111	......	......	62	62	50	1
37	125	61	80	108	105	51	59	42	36	36	38	25	27	25	31
41	38	80	55	105	100	66	55	49	40	37	37	24	33	24	40
42	......	......	......	......	143	133	95	102	95	66	43	24	50	38	40
43	26	26	23	......	......	15	17	17	12	11	5	20	2	1	1
47	43	19	40	......	......	36	33	44	31	21	......	21	13	8	5
48	......	......	......	......	......	24.4	29	35	27	32	......	14	28	20	21

TABLE NO. 13.

Nitrates Percolated, Parts Per Million, 1911.

Pot Number.	July.		Aug.	October.			November.		December.				January, 1912.		
	10th.	20th.	22nd.	4th.	16th.	24th.	10th.	16th.	13th.	18th.	24th.	28th.	1st	4th.	6th.
1	......	37.7	......	......	......	......	4.3	......	83.3	102.5	78.4	67.8	85.1	......	......
5	......	51.2	......	......	......	......	90.9	......	86.9	90.9	95.2	40.0	22.9	......	......
6	......	40.0	......	......	72.7	......	83.3	59.6	95.2	88.8	53.3	21.0	10.2	......	......
7	......	3.4	......	......	......	......	2.1	......	8.3	173.9	121.2	117.6	114.3	......	......
11	......	......	......	......	......	......	111.1	......	95.2	125.0	148.1	125.0	90.9	......	......
12	......	6.3	......	......	2.2	......	2.0	......	6.8	170.8	100.0	95.2	81.6	......	......
13	......	50.0	39.4	29.8	50.6	46.5	74.1	74.0	45.4	67.8	49.3	44.9	33.3	34.8	......
17	......	64.5	85.1	27.0	88.8	74.0	80.0	83.3	63.5	56.3	32.6	25.0	16.6	14.2	......
18	......	57.1	86.9	33.5	80.0	74.0	90.0	80.0	40.8	66.6	51.7	33.9	25.0	25.9	......
19	......	66.6	115.0	20.0	129.0	105.2	153.8	166.6	90.9	102.5	54.7	45.4	37.9	40.5	......
23	......	68.2	137.9	75.4	133.3	105.2	173.9	190.4	117.6	85.1	51.2	25.3	13.3	12.2	......
24	......	36.3	90.9	6.2	95.2	......	153.8	......	137.9	137.9	81.6	81.6	64.5	......	......
25	......	45.4	173.9	......	102.5	......	210.5	235.3	200.0	235.3	142.8	114.2	114.3	81.6	......
29	......	52.6	190.4	5.4	160.0	102.5	235.3	250.0	222.2	250.0	133.3	125.0	93.0	78.4	......
30	......	44.4	83.3	......	108.1	......	166.6	181.8	235.3	266.6	160.0	166.6	95.2	102.5	......
31	......	33.3	......	......	75.4	......	111.1	114.2	105.2	148.1	95.2	83.3	48.7	......	......
35	......	14.4	......	......	81.6	......	111.1	125.0	153.8	200.0	114.2	88.8	72.7	......	......
36	......	52.6	......	......	11.6	......	4.8	......	166.6	190.4	97.5	105.2	85.1	......	......
37	66.0	45.4	153.8	......	138.0	......	253.3	190.4	160.0	166.6	52.6	74.0	58.8	57.1	......
41	......	45.4	235.3	......	173.9	......	253.3	190.4	181.8	200.0	102.5	100.0	86.9	93.0	......
42	......	31.7	105.3	......	148.1	......	210.5	222.2	210.5	250.0	125.0	105.2	95.2	74.0	......
43	......	31.7	......	4.2	54.0	47.0	86.9	76.9	80.0	93.0	51.2	53.3	42.5	45.9	47.0
47	......	45.4	......	......	88.8	......	105.2	100.0	95.2	105.2	71.4	66.6	49.3	48.7	......
48	......	31.7	......	......	83.3	......	108.1	102.5	117.6	133.3	81.6	74.0	62.5	56.3	......

TABLE NO. 13.

Nitrates Percolated, Parts Per Million, 1912.

Pot Number.	Jan.	February.		March.				April.			May	June.			July	Aug.
	16th.	19th.	28th.	7th.	18th.	23rd.	27th.	6th.	11th.	17th.	9th.	3rd.	15th.	25th.	25th.	
1	91.7	......	50.6	37.5	18.1	11.9	6.3	1.3	1.3	......	1.4	......	......	......	......	......
5	12.8	......	12.2	14.2	9.3	9.2	11.3	12.8	13.3	1.2	......	7.9	......	0.5	3.0	......
6	5.7	......	3.1	4.6	3.2	6.6	5.5	4.2	3.4	......	......	2.7	0.1	0.5	......	......
7	74.1	12.0	54.0	51.9	34.4	20.4	11.3	12.3	8.4	3.8	0.7	......	......	......	0.5	......
11	75.4	......	57.9	41.9	26.3	16.1	11.2	13.3	13.2	3.0	......	14.0	11.2	......	1.0	......
12	65.5	4.2	54.7	57.1	40.0	30.3	8.7	11.6	7.5	1.3	......	......	......	1.3	......	......
13	42.2	23.0	13.5	15.8	9.5	8.2	4.7	4.8	5.3	3.0	4.5	12.6	5.2	0.5	12.0	......
17	15.8	10.9	11.3	13.4	6.9	7.5	4.9	7.0	8.2	5.9	9.1	28.1	10.0	5.5	......	......
18	28.1	25.9	12.2	14.7	8.8	8.4	4.8	6.5	6.6	4.5	5.5	20.0	6.9	......	16.0	......
19	43.0	27.3	25.9	25.6	12.9	11.9	5.9	8.1	8.0	7.0	10.5	20.0	13.1	8.9	17.0	......
23	12.9	11.2	9.4	10.7	6.7	7.5	4.0	6.9	8.0	2.3	8.8	17.0	15.6	12.0	28.0	......
24	83.3	34.0	43.0	35.3	7.4	12.5	3.8	10.4	11.1	1.5	12.5	25.0	17.8	13.0	34.8	......
25	85.1	80.0	68.9	75.4	33.3	38.4	12.5	20.0	20.0	7.2	8.1	29.0	0.8	......	21.0	......
29	78.4	70.1	71.4	61.5	31.7	32.2	10.6	18.8	16.6	8.7	16.1	31.2	12.8	......	47.1	......
30	100.0	95.2	86.9	81.6	45.4	39.2	10.1	18.1	14.9	8.5	14.2	33.3	5.3	......	18.0	......
31	34.8	......	23.5	26.3	6.8	8.5	3.0	3.2	4.5	......	10.9	......	......	0.5	7.5	......
35	63.5	......	44.4	48.2	12.8	15.1	7.5	13.1	13.9	7.2	.9	......	......	......	14.0	......
36	......	......	......	37.5	13.9	20.4	8.9	12.5	9.0	......	3.2	0.5	0.8	......	27.0	......
37	65.5	46.5	37.5	31.9	13.3	12.3	6.4	8.0	9.1	5.4	7.9	27.0	37.2	......	46.3	......
41	86.9	80.0	66.6	58.9	16.6	11.9	5.5	9.5	9.0	3.8	7.7	23.5	13.5	......	38.0	......
42	83.3	57.9	64.5	62.5	15.8	13.1	6.9	11.9	12.0	7.0	8.7	20.0	8.1	19.0	40.0	......
43	48.7	44.4	51.9	64.5	29.0	35.7	10.9	40.0	16.6	9.0	......	12.0	10.4	0.5	27.0	......
47	56.3	43.4	44.4	57.1	21.0	12.2	6.5	14.9	11.7	6.8	10.0	3.1	7.3	......	8.0	......
48	61.5	8.4	57.1	54.7	33.3	29.4	7.9	16.6	15.1	14.7	4.4	18.8	12.0	......	......	......

TABLE NO. 13.

Nitrates Percolated, Parts Per Million, 1912.

Pot Number.	Sept.	Oct.	Nov.	December.						
			25th.	6th.	12th.	17th.	31st.	23rd.	28th.	31st.
1	......	......	5.0	0.3	......	7.6	......	......	79.5	......
5	......	......	5.0	0.3	83.3	32.3	......	100.0	112.5	106.5
6	......	......	......	......	......	117.0	......	100.0	88.5	84.0
7	......	......	5.0	0.3	......	0.2	......	100.0	150.0	135.0
11	......	......	5.0	......	......	12.8	......	100.0	166.7	161.3
12	......	......	......	......	......	0.2	......	200.0	166.7	150.0
13	......	......	5.0	24.4	33.0	17.3	......	166.6	15.0	24.0
17	......	......	8.0	36.4	57.7	57.2	......	113.6	31.5	39.0
18	......	......	95.0	26.4	60.0	45.4	......	125.0	33.0	43.5
19	......	......	9.0	64.5	83.3	60.9	......	104.1	73.5	88.5
23	......	......	10.0	62.5	90.9	74.4	......	219.8	79.5	109.5
24	......	......	......	69.0	96.8	21.1	......	250.0	103.5	......
25	......	......	20.0	......	120.0	203.0	......	210.5	217.4	230.8
29	......	......	35.0	69.0	100.0	227.3	......	215.0	194.8	150.0
30	......	......	25.0	83.4	111.1	214.2	......	......	192.4	......
31	......	......	8.0	10.0	43.5	67.5	......	104.1	69.0	75.0
35	......	......	10.0	......	......	72.0	......	259.7	94.5	......
36	......	......	......	......	......	48.0	......	......	57.0	......
37	......	......	20.0	83.4	85.7	117.0	......	106.3	87.0	......
41	......	......	15.0	60.6	79.0	158.0	......	222.2	172.5	185.2
42	......	......	......	80.0	93.8	176.4	......	184.0	166.7	136.5
43	......	......	5.0	25.0	......	52.5	40.5	......	48.0	55.5
47	......	......	5.0	......	......	60.0	......	111.1	66.0	73.5
48	......	......	......	......	......	217.5	......	263.1	82.5	......

TABLE NO. 13.

Nitrates, Parts Per Million, 1913.

Pot Number.	January.				February.				March.				April.		
	10th.	14th.	25th.	28th.	1st.	10th.	15th.	24th.	3rd.	12th.	17th.	25th.	7th.	12th.	28th.
1	......	15.0	......	48.0	......	......	27.0	......	......	4.0	4.0	......	......	......	1.0
5	......	42.0	68.0	49.0	......	17.0	6.0	......	4.0	6.0	4.5	......	2.5	2.5	5.0
6	......	36.0	50.0	36.0	......	11.0	6.0	......	6.0	5.5	5.0	......	3.5	5.0	5.0
7	......	......	88.0	100.0	......	51.0	38.0	......	18.0	15.5	14.0	......	3.0	......	0.5
11	......	67.5	163.9	147.0	......	67.0	38.0	......	22.5	16.0	9.5	......	......	5.5	8.0
12	......	......	138.9	137.0	......	58.0	34.0	......	17.5	19.0	15.0	......	2.0	6.0	9.0
13	......	12.0	20.0	9.0	......	4.0	2.0	3.0	5.0	3.5	3.0	......	2.5	......	5.0
17	......	22.5	42.0	26.0	......	15.0	15.0	17.0	17.5	12.0	7.5	7.5	15.0	8.5	11.5
18	......	13.5	32.0	13.0	......	5.0	7.0	......	7.5	10.0	6.5	......	14.0	12.0	13.0
19	......	40.5	78.0	55.0	......	23.0	15.0	......	10.0	8.5	7.5	......	12.5	10.0	13.0
23	......	49.5	80.0	60.0	......	42.0	36.0	......	21.0	18.0	16.5	......	2.5	8.0	11.5
24	......	......	......	79.0	......	42.0	39.0	......	13.0	20.0	20.0	......	3.5	......	10.5
25	......	93.0	185.3	164.0	......	64.0	46.0	......	36.0	25.0	18.0	......	2.0	......	15.5
29	......	93.0	135.6	131.6	......	83.0	55.0	......	55.6	37.5	32.0	......	79.4	32.0	40.0
30	......	82.5	114.9	153.9	......	......	80.0	......	50.0	35.0	32.5	......	75.8	33.0	34.0
31	......	......	55.0	43.0	......	15.0	11.0	......	6.0	7.5	4.5	......	15.0	......	......
35	......	......	......	99.0	......	......	40.0	......	......	22.0	20.0	......	......	......	......
36	......	3.0	......	54.0	......	......	43.0	......	......	21.5	22.5	......	......	......	......
37	......	43.5	......	70.0	......	70.0	79.0	......	36.0	32.0	32.5	......	49.0	32.5	21.0
41	......	87.0	181.8	147.0	......	73.0	86.0	......	3.8	35.0	23.0	......	4.5	7.0	13.0
42	......	88.5	60.0	147.0	......	75.0	66.0	......	37.5	32.5	37.5	......	42.5	30.0	31.5
43	48.0	31.5	73.0	620.0	54.0	......	47.0	42.5	26.0	25.0	30.0	22.5	......	5.5	18.5
47	......	18.0	149.2	57.0	53.0	......	42.0	35.0	26.0	22.5	22.0	......	......	......	9.0
48	......	......	......	45.0	......	......	40.0	......	......	25.0	20.0	......	5.0	......	10.0

TABLE NO. 13.

Nitrates Removed in Parts Per Million In 1913.

Pot Number.	May.		July	October.			November.		December.									Jan. 1st. (1914)
	19th.	26th.	5th.	2nd.	7th.	20th.	10th.	27th.	2nd.	4th.	4th. No. 2.	4th. No. 3.	5th.	6th.	10th.	16th.	27th.	
1	......	0.4	......	13.4	......	......	......	......	18.0	20.0	......	......	......	......	0.5	2.0	......	......
5	......	7.0	0.7	61.6	24.0	26.0	1.0	24.0	59.0	7.0	......	......	......	......	......	......	......	......
6	3.0	7.6	2.0	46.4	107.0	112.0	90.0	55.0	18.0	7.0	1.0	1.0	......	......	......	......	......	......
7	......	0.6	1.2	2.4	56.0	......	12.0	6.0	74.0	60.0	30.0	......	6.0	......	4.0	......	2.5	2.0
11	......	9.4	0.7	52.0	78.0	124.0	80.0	120.0	112.0	58.0	1.0	......	......	......	......	......	......	......
12	......	3.0	......	44.6	70.0	128.0	148.0	128.0	74.0	23.0	1.0	......	......	......	......	......	0.5	1.0
13	0.8	6.2	0.6	31.2	32.0	26.0	21.0	20.0	9.0	2.0	1.0	......	1.0	......	4.0	14.0	5.0	2.0
17	4.0	7.0	......	54.0	55.0	48.0	46.0	40.0	18.0	2.0	......	......	4.0	......	8.0	20.0	8.5	4.5
18	0.4	7.4	0.5	49.2	53.0	41.0	33.0	30.0	17.0	3.0	1.0	......	1.0	......	4.0	12.0	7.0	4.5
19	4.0	16.8	0.4	45.6	68.0	68.0	73.0	67.0	49.0	3.0	......	......	......	......	2.0	4.0	3.0	3.0
23	2.0	14.0	0.5	49.8	86.0	88.0	76.0	62.0	48.0	7.0	......	......	4.0	......	4.0	4.0	3.0	4.0
24	......	1.0	......	48.0	......	15.0	29.0	60.0	90.0	14.0	......	......	......	......	3.5	......	2.5	3.5
25	1.2	1.6	0.7	49.6	72.0	93.0	104.0	128.0	96.0	88.0	......	......	6.0	......	9.0	9.0	8.5	7.0
29	0.8	1.4	0.4	80.0	144.0	166.0	156.0	130.0	150.0	63.0	25.0	......	5.0	......	4.0	6.0	6.0	5.0
30	1.0	26.8	0.7	87.0	130.0	140.0	116.0	140.0	120.0	50.0	......	......	......	......	4.5	2.0	3.5	5.0
31	1.0	......	2.0	18.4	43.0	......	8.0	9.0	42.0	11.0	1.0	......	......	......	1.0	2.0	2.0	2.5
35	......	......	......	37.2	100.0	......	......	......	92.0	12.0	......	......	......	......	9.5	......	15.0	10.5
36	......	......	......	77.0	154.0	15.0	......	......	75.0	75.0	......	......	......	......	37.5	......	29.0	24.5
37	0.6	......	......	52.0	104.0	116.0	100.0	93.0	72.0	10.0	......	......	4.0	......	4.0	7.0	6.5	8.0
41	0.8	......	0.7	41.4	84.0	76.0	92.0	106.0	76.0	20.0	......	......	1.0	......	3.0	1.0	3.5	4.5
42	30.8	30.4	0.7	66.0	154.0	116.0	146.0	148.0	80.0	33.0	......	......	12.0	......	17.5	12.0	8.5	8.0
43	......	......	1.9	13.2	24.0	......	30.0	40.0	15.0	9.0	......	......	4.0	5.0	5.5	20.0	8.0	4.5
47	......	1.6	......	40.0	50.0	22.0	49.0	60.0	54.0	60.0	......	......	43.0	......	31.0	77.0	28.5	24.0
48	......	0.6	......	45.0	100.0	20.0	......	85.0	65.0	7.0	......	......	3.0	......	6.0	26.0	22.0	12.0

TABLE NO. 14.

Nitrate in Milligrams, Per Pot Per Month, 1911.

Pot Number.		Feb.	Mar.	April.	May.	July.	Aug.	Oct.	Nov.	Dec.	Total.
1	Norfolk sand	15	45	40	2	14	......	......	......	400	516
5	Norfolk sand, manure October 15	23	17	80	7	29	......	......	168	685	1009
6	Norfolk sand, manure, March 15	......	27	139	19	64	......	136	163	586	1134
7	Orangeburg fine sandy laom	107	18	358	19	......	......	......	......	663	1165
11	Orangeburg fine sandy loam, manure, October 15	167	8	327	26	......	......	......	67	1090	1685
12	Orangeburg fine sandy loam, manure, March 15	......	34	299	17	......	......	......	......	740	1090
13	Houston loam	113	62	134	24	139	18	97	111	457	1155
17	Houston loam, manure, October 15	134	75	133	25	187	64	211	191	439	1459
18	Houston loam, manure, March 15	......	61	127	25	173	52	167	134	422	1161
19	Houston black clay	315	126	194	38	210	100	206	289	679	2157
23	Houston black clay, manure, October 15	214	123	200	50	196	103	349	353	671	2259
24	Houston black clay, manure, March 15	......	117	98	14	112	64	221	192	797	1605
25	Yazoo clay	450	400	425	65	89	83	208	281	1477	3478
29	Yazoo clay, manure, October 15	379	369	544	89	135	100	303	396	1609	3924
30	Yazoo clay, manure, March 15	......	279	431	68	104	46	170	257	1635	2990
31	Miller fine sandy loam	101	66	370	33	33	......	23	30	833	1489
35	Miller fine sandy loam, manure, October 15	85	72	350	32	21	......	37	166	1106	1869
36	Miller fine sandy loam, manure, March 15	......	59	141	4	13	......	1	......	217	435
37	Crawford clay	386	196	266	38	152	177	359	444	1045	3063
41	Crawford clay, manure, October 15	348	193	289	79	155	188	443	480	1420	3595
42	Crawford clay, manure, March 15	......	314	531	92	101	84	330	390	1473	3315
43	Lufkin fine sandy loam	40	5	69	4	41	......	54	58	445	716
47	Lufkin fine sandy loam, manure, October 15	36	112	91	9	84	......	89	145	687	1253
48	Lufkin fine sandy loam, manure, March 15	......	67	192	23	43	......	67	56	751	1199

6, 12, 18, 24, 30, 36, 42, 48, nitrate not begun until after manure added, March 15th.

TABLE NO. 14.

Nitrate in Milligrams Per Pot Per Month, 1912.

Pot Number.		Jan.	Feb.	Mar.	April.	May.	June.	July.	Nov.	Dec.	Total.
1	Norfolk sand	4.6	20.2	76.9	3.3	0.1	......	......	......	26.7	131.8
5	Norfolk sand, manure, October 15	3.2	11.6	61.5	44.3	......	1.0	0.9	......	388.4	510.9
6	Norfolk sand, manure, March 15	1.6	2.9	39.1	11.8	......	1.7	......	......	355.3	412.4
7	Orangeburg fine sandy loam	5.9	9.2	174.7	28.0	0.1	......	......	......	177.3	395.2
11	Orangeburg fine sandy loam, manure, October 15	18.8	91.5	144.3	46.6	......	6.5	0.1	......	228.2	536.0
12	Orangeburg fine sandy loam, manure, March 15	8.2	18.3	230.5	26.9	......	......	......	......	295.0	578.9
13	Houston loam	15.8	39.2	55.3	20.0	3.5	23.4	0.7	......	419.0	576.9
17	Houston loam, manure, October 15	4.6	25.2	60.3	30.9	8.2	60.0	......	0.1	439.8	629.1
18	Houston loam, manure, March 15	5.6	19.3	56.0	20.4	3.5	37.9	5.6	0.2	380.0	528.5
19	Houston black clay	8.6	66.4	107.5	31.2	9.9	41.8	3.6	......	543.1	812.1
23	Houston black clay, manure, October 15	3.3	26.4	55.4	29.0	8.8	38.7	13.3	0.1	832.8	1007.8
24	Houston black clay, manure, March 15	1.2	50.0	108.7	31.0	7.7	48.3	13.9	......	495.6	756.4
25	Yazoo clay	3.8	127.9	262.2	69.9	4.4	40.0	1.5	......	877.8	1380.5
29	Yazoo clay, manure, October 15	5.5	154.2	221.6	57.3	12.1	53.4	10.8	0.2	840.6	1355.7
30	Yazoo clay, manure, March 15	7.5	148.4	283.4	42.1	9.2	45.4	0.5	......	362.3	898.8
31	Miller fine sandy loam	6.6	8.5	59.3	14.0	0.1	......	0.5	0.1	334.1	423.2
35	Miller fine sandy loam, manure, October 15	2.8	17.3	96.5	46.7	......	......	1.7	......	291.6	456.6
36	Miller fine sandy loam, manure, March 15	......	......	16.0	4.7	0.2	......	0.9	......	11.5	33.3
37	Crawford clay	13.1	98.4	93.0	29.7	8.3	65.3	34.4	......	557.1	899.3
41	Crawford clay, manure, October 15	20.8	191.2	151.7	36.3	8.2	60.3	29.8	......	796.7	1295.0
42	Crawford clay, manure, March 15	14.1	130.5	137.7	38.2	7.4	40.1	19.4	......	734.5	1121.9
43	Lufkin fine sandy loam	28.0	24.0	86.9	95.5	2.8	11.1	1.1	0.1	199.0	448.5
47	Lufkin fine sandy loam, manure, October 15	6.2	17.6	97.4	66.1	......	8.1	0.1	0.1	302.6	498.2
48	Lufkin fine sandy loam, manure, March 15	2.5	22.1	127.6	52.7	0.2	13.3	......	......	301.2	519.6

TABLE NO. 14.

Nitrates Percolated in Milligrams Per Pot in 1913.

Pot Number.		Jan.	Feb.	Mar.	April.	May.	July.	Oct.	Nov.	Total.	Dec.
1	Norfolk sand	7.0	0.7	0.8	......	.01	......	0.8	......	9.3	0.6
5	Norfolk sand, manure, October 15	133.2	47.5	22.7	3.2	2.87	.021	80.2	0.6	290.3	51.5
6	Norfok sand, manure, March 15	93.6	27.4	21.8	9.1	6.20	.03	150.5	200.9	509.5	31.5
7	Orangeburg fine sandy loam	250.6	152.3	48.0	0.1	.01	.036	3.6	0.6	455.2	51.5
11	Orangeburg fine sandy loam, manure, October 15	370.7	203.3	69.2	7.1	3.00	.014	93.9	19.6	766.8	50
12	Orangeburg fine sandy loam, manure, March 15	351.7	168.5	58.1	6.3	.84	......	84.7	290.8	960.9	53
13	Houston loam	26.7	12.6	14.5	4.1	1.55	.024	109.5	29.0	211.9	49
17	Houston loam, manure, October 15	77.2	57.6	54.0	18.5	4.38	......	239.2	92.7	543.6	83
18	Houston loam, manure, March 15	35.9	18.3	32.5	24.5	1.70	.035	165.4	71.2	349.5	78
19	Houston black clay	162.1	78.0	42.2	17.5	7.49	.036	206.9	132.7	646.9	151
23	Houston black clay, manure, October 15	199.6	154.3	92.7	14.1	5.55	.03	224.3	139.9	830.5	164
24	Houston black clay, manure, March 15	136.6	105.1	51.9	4.0	.02	.021	11.8	6.9	316.3	143
25	Yazoo clay	422.4	200.9	98.3	10.2	.08	.021	222.2	198.2	1152.3	633
29	Yazoo clay, manure, October 15	348.7	267.3	175.1	50.1	.01	.012	372.6	276.1	1489.9	699
30	Yazoo clay, manure, March 15	285.6	175.2	109.1	47.9	.27	.028	118.8	66.6	803.5	72
31	Miller fine sandy loam	113.2	49.1	21.2	0.5	......	.04	8.8	0.9	193.7	137
35	Miller fine sandy loam, manure, October 15	144.5	42.0	10.9	......	......	......	22.9	......	220.3	57
36	Miller fine sandy loam, manure, March 15	2.8	0.9	1.1	......	......	......	154.5	......	159.3	17
37	Crawford clay	160.8	242.2	152.4	40.8	......	......	257.4	206.6	1060.2	251
41	Crawford clay, manure, October 15	355.7	268.3	156.2	13.3	......	.021	327.3	155.2	1276.0	291
42	Crawford clay, manure, March 15	365.9	234.5	140.2	43.0	16.45	.042	318.9	264.7	1383.7	370
43	Lufkin fine sandy loam	67.1	175.1	431.9	0.9	......	.038	9.7	12.5	697.2	99
47	Lufkin fine sandy loam, manure, October 15	120.7	135.6	70.1	0.1	.02	......	......	27.9	354.4	455
48	Lufkin fine sandy loam, manure, March 15	32.9	6.8	14.6	0.8	.01	......	......	3.4	58.5	36

QUANTITY OF NITRIC NITROGEN PERCOLATING.

Table No. 16 is a summary of Table No. 14 and shows the total quantities of nitric nitrogen percolating from the uncultivated soil, both those which received no additions and those which received manure.

An examination of the tables show that the concentration of the nitrates in the water percolating from the pots reaches its maximum in the fall, usually in December, and its minimum in the spring, usually in April. This may be due to the accumulation of nitrates during the summer months, when the temperature is favorable to nitrification, and there is little percolation, and to washing the nitrates out by the fall and winter rains. Nitrification is of course less active during the winter months. From Table No. 14, showing the nitrates in milligrams percolated per pot, we likewise see that the nitric nitrogen washed out in December forms a large proportion of the total loss.

NITROGEN LOST IN POUNDS PER ACRE.

The loss of 1 mg. per pot represents a loss of 0.122 pounds per acre. Table No. 15 shows the average loss of nitrogen in pounds per acre per year for the several soils (December, 1913, excluded). The loss varies from 26.7 to 244.2 pounds per acre. The average for the sandy group is 67.2 pounds and for the clay group 168.6. The nitrogen content of soil and subsoil is also stated in the table. It is seen that the loss of nitrates is related to the total nitrogen of the soil. The quantity increases with the content of soil and subsoil in nitrogen. As it takes approximately 1.5 pounds nitrogen for grain, stalk, leaves, etc., for a bushel of corn, we have also calculated the loss of nitrogen to bushels corn per acre. This is 45 bushels for the first group and 114 bushels for the second.

TABLE NO. 15.

Loss of Nitric Nitrogen Per Year Per Acre.

	Pounds per acre.	Per cent nitrogen. Surface.	Per cent nitrogen. Subsoil.	Average of surface and subsoil.	Corn in bushels equal to nitrates.
Norfolk sand....................	26.7	.03	....	.03	18
Orangeburg fine sandy loam......	81.9	.04	....	.04	54
Miller fine sandy loam...........	85.5	.05	.035	.04	57
Lufkin sandy loam...............	75.6	.05	.063	.059	51
Average for group.........	67.2	.044	.044	....	45
Houston loam....................	78.9	.034	.040	.037	51
Houston black clay..............	147.0	.119	.079	.099	99
Yazoo clay......................	244.2	.149	.152	.151	162
Crawford clay...................	203.1	.151	.098	.125	135
Average for group.........	168.6	.113	.092	....	114

While it is not probable that all the nitrates produced were washed from the soil each year, yet the figures ought to give us a fairly good idea of the amount formed. We can also compare these figures with the corn possibility based upon the nitrogen taken up in pot experiments as follows:

	Per cent nitrogen average of soil and subsoil.	Corn equal to nitrates.	Corn possibility of total nitrogen. (Bushels per acre.)
Norfolk sand	.03	18	13
Houston loam	.037	51	13
Orangeburg fine sandy loam	.04	54	18
Miller fine sandy loam	.04	57	18
Average of first group	.044	45	18
Lufkin sandy loam	.059	51	18
Houston black clay	.099	99	28
Average of second group	.092	104	28
Crawford clay	.125	135	38
Yazoo clay	.151	162	43

It is evident that the average quantity of nitrates produced is large. The losses from cropped land would, of course, be much less than these given here. The nitrates formed would be absorbed by the crops. The percolation would be reduced, both by the water evaporated from the crops, and by water running off on the surface.

Nevertheless, considerable losses of plant food may occur from bare, uncropped soils during the winter months. The nitrates are not all taken up by the plants, and a portion of the water percolates from the soil.

NITRATES FROM MANURE.

Table No. 16 shows the nitric nitrogen, in milligrams per pot, percolating from the manured and unmanured pots. As previously stated, manure was added at the rate of 30 grams of dried sheep excrement per pot, on October 15 or March 15. This represented an application of 9.15 tons per acre of manure containing 80 per cent water. The quantity of nitrogen added was equal to 456 milligrams per year, October 15, and 474 milligrams March 15, or 55.6 pounds per acre for the former.

An examination of the table shows that, with one exception, more nitrates percolated from the manure applied October 15 than from that applied March 15. This may be compared with the fact, discussed elsewhere in this Bulletin, that the manure applied October 15 decreased evaporation better than that applied March 15. The difference may be partly due to the fact that some of the pots to which the manure was applied March 15 did not percolate properly.

The average quantity of nitric nitrogen per year produced from the manure applied October 15 is as follows:

	Milligrams per pot.	Pounds per acre.	Sufficient for bushels corn per acre.
Group 1	234	28.5	19
Group 2	256	31.2	21
Average	245	29.8	20

This is 53.7 per cent. of the 456 milligrams nitrogen applied in the manure each year. According to this, an application of 9 tons manure per acre annually would raise the corn possibility (so far as nitrogen is concerned) 20 bushels per acre.

TABLE NO. 16.

Nitrogen Percolated as Nitrates in Milligrams Per Pot.

	No addition.	Manure October 15.	Manure March 15.
Norfolk sand, 1911	516.0	1009.0	1134.0
Norfolk sand, 1912	131.8	510.9	412.4
Norfolk sand, 1913	9.3	209.3	509.5
Average	219.0	603.4	685.3
Orangeburg fine sandy loam, 1911	116.5	168.5	1090.0
Orangeburg fine sandy loam, 1912	395.2	536.0	578.9
Orangeburg fine sandy loam, 1913	455.2	766.8	960.9
Average	671.8	995.9	876.6
Miller fine sandy loam, 1911	1489.0	1869.0	435.0
Miller fine sandy loam, 1912	423.2	456.6	33.3
Miller fine sandy loam, 1913	193.7	220.3	159.3
Average	702.0	848.6	209.2
Lufkin sandy loam, 1911	716.0	1253.0	1199.0
Lufkin sandy loam, 1912	448.5	498.2	519.5
Lufkin sandy loam, 1913	697.2	354.4	58.5
Average	620.6	701.9	592.4
Average for group	553.4	787.5	590.9
Houston loam, 1911	1155.0	1459.0	1161.0
Houston loam, 1912	576.9	629.1	528.5
Houston loam, 1913	211.9	543.6	349.5
Average	647.9	877.2	679.7
Houston black clay, 1911	2157.0	2259.0	1605.0
Houston black clay, 1912	812.1	1007.8	756.4
Houston black clay, 1913	646.9	830.5	316.3
Average	1205.3	1365.8	892.6
Yazoo clay, 1911	3478.0	3924.0	2990.0
Yazoo clay, 1912	1380.5	1355.7	898.8
Yazoo clay, 1913	1152.3	1489.9	803.5
Average	2003.6	2256.5	1564.1
Crawford clay, 1911	3063.0	3595.0	3315.0
Crawford clay, 1912	899.3	1295.0	1121.9
Crawford clay, 1913	1060.2	1276.0	1383.7
Average	1674.2	2055.3	1940.2
Average for group	1382.8	1638.7	1269.2

TABLE NO. 17.

Nitrates Percolated Parts per Million 1912 (March 23 to December 31.)

Pot Number.		March 23d.	March 27th.	April 6th.	April 11th.	April 17th.	May 9th.	June 3rd.	June 15th.	June 25th.	July 25th.	August.	September.	October.	November 25.	December 6th.	December 12th.	December 17th.	December 31st.	December 23rd.	December 28th.	December 31st.
1	Norfolk sand, 0″	11.9	6.3	1.3	1.3	....	1.4	....	....	....	....	..	..	..	5.0	0.3	.....	7.6	.....	.....	79.5	.....
2	Norfolk sand, 2″ and nitrates	8.0	8.9	6.3	12.5	8.9	33.3	40.0	....	....	28.5	..	..	..	10.0	36.4	41.1	20.0	.....	50.0	72.0	.....
7	Orangeburg fine sandy loam, 0″	20.4	11.3	12.3	8.4	3.8	.7	....	....	....	0.5	..	..	..	5.0	0.3	.....	0.2	.....	100.0	150.0	105.0
8	Orangeburg fine sandy loam, 2″ and nitrates	7.9	7.3	9.0	16.6	35.7	35.3	31.5	....	....	....	..	..	..	.....	.....	.....	66.7	.....	107.5	117.0	189.5
13	Houston loam, 0″	8.2	4.7	4.8	5.3	3.0	4.5	12.6	5.2	0.5	12.0	..	..	..	5.0	24.4	33.0	17.3	.....	166.6	15.0	24.0
14	Houston loam, 2″ and nitrates	9.6	6.9	15.1	28.5	28.1	27.4	33.3	25.0	20.0	38.0	..	..	..	100.0	33.3	.....	144.0	52.5	.....	45.0	58.5
19	Houston black clay, 0″	11.9	5.9	8.1	8.0	7.0	10.5	20.0	13.1	8.9	17.0	..	..	..	9.0	64.5	83.3	60.9	.....	104.1	73.5	88.5
20	Houston black clay, 2″ and nitrates	16.6	11.7	38.9	38.0	29.0	30.3	31.2	30.0	15.0	34.0	..	..	..	83.0	80.0	96.8	86.3	.....	212.8	117.0	150.5
25	Yazoo clay, 0″	38.4	12.5	20.0	20.0	7.2	8.1	29.0	0.8	....	21.0	..	..	..	20.0	.....	120.0	203.0	.....	210.5	217.4	230.8
26	Yazoo clay, 2″ and nitrates	21.7	11.5	58.8	85.1	66.6	47.0	43.9	28.5	....	....	..	..	..	30.0	76.9	93.8	234.5	.....	219.8	217.4	.....
31	Miller fine sandy loam, 0″	8.5	3.0	3.2	4.5	....	0.9	....	....	0.5	7.5	..	..	..	8.0	10.0	43.5	67.5	.....	104.1	69.0	75.0
32	Miller fine sandy loam, 2″ and nitrates	78.8	59.0	60.6	64.5	66.6	45.4	56.6	60.6	1.5	9.0	..	..	..	75.0	.....	62.5	97.5	.....	263.8	93.0	.....
37	Crawford clay, 0″	12.3	6.4	8.0	9.1	5.4	7.9	27.0	37.2	....	46.3	..	..	..	20.0	83.4	85.7	117.0	.....	106.3	87.0	.....
38	Crawford clay, 2″ and nitrates	12.8	8.0	29.5	50.0	53.3	46.1	50.6	....	2.5	7.0	..	..	..	.....	83.4	111.1	202.7	.....	208.3	189.9	120.0
43	Lufkin sandy loam, 0″	35.7	10.9	40.0	16.6	9.0	10.0	12.0	10.4	0.5	27.0	..	..	..	5.0	25.0	.....	52.5	40.5	.....	48.0	55.5
44	Lufkin sandy loam, 2″ and nitrates	24.1	8.4	37.9	43.4	44.4	35.0	41.6	51.0	9.5	38.0	..	..	..	20.0	57.2	.....	72.5	76.5	.....	82.5	81.0

The results here given show a high nitrification of the manure accompanied with a high percolation of the nitrates produced. The manure applied was dry, finely ground sheep excrement, and should not nitrify as readily as ordinary barnyard manure, which has usually fermented to some extent.

LOSS OF NITRATES BY PERCOLATION.

On March 15, 1912, and again on November 15, 1 gram nitrate of soda containing 152 mg. nitrogen was added to four cultivated pots, Nos. 2, 8, 14 and 20, and two grams were added to four others, of different soils, Nos. 26, 32, 38 and 44. The object of the application was to ascertain how rapidly the nitrates would percolate. The additions made were at the rate of 122 and 244 pounds nitrate of soda per acre.

Table No. 17 shows a comparison in parts per million of nitric nitrogen of these pots and the soils receiving no additions. With two of the soils, an increase in the proportion of nitrates is seen at once, but with the other six the nitrates had no effect on the percolating water until the collection of April 6th or April 11th, the third or fourth percolation since the nitrates were added. The loss of nitrogen in milligrams per month for the year is shown in Table No. 18.

TABLE NO. 18.

Milligrams Nitric Nitrogen Removed Per Pot, 1912.

Pot Number.		March 23rd and 27th.	April.	May.	June.	July.	November.	December.	Total.
1	Norfolk sand, 0....................	36.9	3.3	0.1	.....	.....	.....	26.7	67.0
2	Norfolk sand, 2.. and nitrates.......	30.8	29.9	41.6	76.0	13.5	.....	241.8	433.6
7	Orangeburg fine sandy loam, 0.......	32.6	28.0	0.1	.....	.....	.....	177.3	238.0
8	Orangeburg fine sandy loam, 2.. and nitrates........................	70.8	54.5	20.5	46.0	.....	.....	312.5	504.3
13	Houston loam, 0....................	15.5	20.0	3.5	23.4	0.7	.....	419.0	482.1
14	Houston loam, 2.. and nitrates.......	12.4	10.0	28.3	69.8	14.4	1.2	273.3	499.7
19	Houston black clay, 0..............	49.6	31.2	9.9	41.8	3.6	.....	543.1	679.2
20	Houston black clay, 2.. and nitrates. .	71.3	123.0	30.3	64.6	15.0	0.2	787.1	1091.5
25	Yazoo clay, 0...	128.3	62.9	4.4	40.0	1.5	.....	877.8	1114.9
26	Yazoo clay, 2.. and nitrates.........	84.6	276.3	39.9	78.5	.....	.....	788.0	1267.3
31	Miller fine sandy loam, 0...........	16.4	14.0	0.1	.....	0.5	0.1	334.1	365.2
32	Miller fine sandy loam, 2.. and nitrates	192.8	179.9	18.2	43.2	0.2	0.2	599.1	1033.6
37	Crawford clay, 0...................	17.8	29.7	8.3	65.3	34.4	.....	557.1	712.6
38	Crawford clay, 2.. and nitrates......	40.4	49.5	35.5	62.2	0.1	.....	776.5	964.2
43	Lufkin sandy loam, 0...............	14.7	95.5	2.8	11.1	1.1	0.1	199.0	324.3
44	Lufkin sandy loam, 2.. and nitrates. .	13.9	172.6	17.5	42.0	1.0	.....	414.2	661.2

The difference in the nitrates from these pots is due, however, not only to the addition of nitrates, but also to the cultivation, the pots to which the nitrates were added being cultivated, and the pots to which no addition was made not being cultivated. It is difficult to allow for this difference. The cultivation caused a greater percolation through a number of the pots, and consequently a greater removal of the nitrates. There appears to be little danger of loss of nitrates during the growing reason.

PERCOLATION OF POTASH.

One gram sulphate of potash was added to pots Nos. 4, 10, 16, 22, 28, 34, 40 and 46 on October 15, 1910, 1911, 1912 and 1913. In addition, two grams were added to pots Nos. 4, 10, 16 and 22 and four grams to 28, 34, 40 and 46 on March 15, 1912. The object of these extra additions was to see if they increased the loss of potash. The sulphate of potash used contained 50.1 per cent. potash (K_2O). One gram of sulphate of potash is equal to an application of 122 pounds per acre of sulphate of potash, or 61 pounds actual potash per acre.

The parts per million of potash in the percolates is given in Table No. 19. The addition of fertilizer potash increased the potash content of the percolates in several instances.

TABLE NO. 19.

Parts Per Million of Potash in Percolates.

Pot Number.		Potash.						
		Jan. 1, 1911, to April 1, 1911.	April 1, 1911, to June 17, 1911.	June 17, 1911, to Jan. 1, 1912.	Jan. 1, 1912, to July 1, 1912.	July 1, 1912, to Jan. 1, 1913.	Jan. 1, 1913, to July 1, 1913.	July 1, 1913, to Dec. 1, 1913.
1	Norfolk sand	14	......	17	9	......	......	......
4	Norfolk sand and potash	16	19	15	11	18	9.1	11.6
7	Orangeburg fine sandy loam	27.7	30	26	22	26	17.1	24.3
10	Orangeburg fine sandy loam and potash	32	33	27	22	......	20.5	21.9
13	Houston loam	7	9	8	6	5	4.2	8.2
16	Houston loam and potash	11	9	7	4	7	4.8	10.9
19	Houston black clay	3	4	5	5	3	2.2	5.5
22	Houston black clay and potash	2	......	5	5	......	......	......
25	Yazoo clay	36	31	31	22	28	16.0	25.9
28	Yazoo clay and potash	33	29	33	20	30	18.8	31.7
31	Miller fine sandy loam	24	26	24	24	17	11.7	20.9
34	Miller fine sandy loam and potash	34	41	32	30	36	26.9	29.8
37	Crawford clay	17	13	16	12	12	3.0	12.6
40	Crawford clay and potash	22	13	17	15	15	3.0	14.7
43	Lufkin fine sandy loam	2	4	4	5	3	2.1	5.4
46	Lufkin fine sandy loam and potash	3	4	6	13	6	2.6	8.1

Table No. 20 shows the potash, in mgr., percolating from the untreated soils, and those which received potash. In considering the potash applied, that introduced October 15, 1910, is excluded. The maximum loss in the three years on any one soil, is 303 mg. with the Norfolk sand, which is 12 per cent. of the potash added. Next comes the Miller fine sandy loam, 142 mg. or 4 per cent. of that added, and the Lufkin fine sandy loam, 4.5 per cent. loss. The Crawford clay lost a little less than 2 per cent., the Orangeburg fine sandy loam 2.2 per cent., the Yazoo clay 0.3 per cent. and the Houston loam and Houston black clay, none.

TABLE NO. 20.

Potash in Milligrams Per Part from Untreated Soils and Soils Which Received Potash.

	No addition.				Potash added.			Loss.				Potash added, Mgs.
	1911	1912	1913	Total.	1911	1912	1913	1911	1912	1913	Total.	
Norfolk sand	165	75	....	240	281	162	101	115	87	101	303	2500
Orangeburg fine sandy loam	371	261	156	788	450	235	159	79	....	3	55	2500
Houston loam	236	123	98	457	230	95	112	....	....	14	......	2500
Houston black clay	141	104	69	214	33	28	....	....	....	....	......	2500
Yazoo clay	851	438	350	1639	845	412	390	....	....	40	14	3500
Miller fine sandy loam	508	323	138	959	506	368	247	....	45	109	142	3500
Crawford clay	567	253	129	949	577	285	150	10	32	21	63	3500
Lufkin fine sandy loam	73	58	24	145	94	168	51	21	110	27	158	3500

We must take into consideration the fact that these soils were uncropped and uncultivated, and that all the water which fell on the soil either evaporated or went through. Growing crops would, of course, use the potash in solution, and decrease the percolation of water, as they evaporate it also. Hence the loss of potash due to the fertilizer would be less on a cropped soil. We should judge from these results that there is little loss of potash of fertilizer, due to percolation, when the potash is applied to a soil on which crops are growing. Even on the light sandy soil, the Norfolk sand, there should be only small loss, if any.

Table No. 21 shows the loss of potash in pounds per acre, from the uncultivated, unfertilized, uncropped soils, to which no fertilizer had been applied. The loss varies from 9.7 to 66.6 pounds per acre. These losses would, of course, be much less when crops are grown on the soil.

TABLE NO. 21.

Average Loss Per Year in Pounds Per Acre.

	Potash.	Lime.	Magnesia.
Norfolk sand	9.7	70.4	13.0
Orangeburg fine sandy loam	32.1	181.0	26.8
Houston loam	18.5	258.1	46.8
Houston black clay	8.2	441.7	40.5
Yazoo clay	66.6	582.0	51.1
Miller fine sandy loam	39.0	259.0	49.2
Crawford clay	38.6	569.0	43.3
Lufkin fine sandy loam	58.6	172.0	52.7

Let us assume that a bushel of corn requires one pound of potash. Then the quantity of potash lost by percolation would produce the quantity of corn given in the following table. We also give the average active potash content of these soils, and the corn possibility as based on the active potash:

	Corn equal to potash removed in percolate.	Active potash of soil.	Corn possibility of active soil potash.
Houston black clay	8.7	362	157
Norfolk sand	9.7	69	37
Houston loam	18.5	134	51
Orangeburg fine sandy loam	32.1	153	80
Crawford clay	38.6	515	182
Miller fine sandy loam	39.0	275	120
Lufkin fine sandy loam	58.6	280	120
Yazoo clay	66.6	911	230

There is little relation between these figures, except that, in a general way, with the exception of the Houston black clay, a higher percentage of active potash is accompanied by a higher percolation of potash. The percolation of potash depends, however, not only on the solubility of the soil potash but also on the fixing power of the soil, and, as we have seen, the fixing powers of these soils are such as to reduce to a minimum the loss of fertilizer potash by percolation, except with the Norfolk sand. It is of some interest to note, however, the quantities of potash which percolated from the uncultivated soil. It is evident that losses of soil potash take place during the winter and spring months, when there are often heavy rains, and the soils are not covered with crops.

PHOSPHORIC ACID.

The quantity of phosphoric acid in some of the percolates is given in Table No. 22, but the quantities are very small. The maximum quantity lost in 1913 is 11.5 milligrams, or about 1.5 pounds per acre. The average quantity lost is 4.1 mg. per pot or 0.5 pounds per acre. These figures serve to show the small losses of phosphoric acid from these unfertilized soils.

LIME.

As was to be expected, large losses of lime occurred. Table No. 23 shows the lime and magnesia in parts per million, and Table No. 24 in milligrams per pot. With one exception, the addition of potash increased the loss of lime, although the increase is slight with several of the soils.

TABLE NO. 22.

Phosphoric Acid in Percolates.

Pot Number.		Parts per million.			Magnesia per pot.			
		July 1, 1912, to Jan. 1, 1913.	Jan. 1, 1913, to July 1, 1913.	July 1, 1913, to Dec. 1, 1914.	July 1, 1912, to Jan. 1, 1913.	Jan. 1, 1913, to July 1, 1913.	July 1, 1913, to Dec. 1, 1914.	Total, 1913.
1	Norfolk sand	......	......	......	......	......	......	......
4	Norfolk sand and potash	......	0.3	0.3	......	2.7	0.5	3.2
7	Orangeburg fine sandy loam	......	0.2	0.2	......	1.8	0.2	2.0
10	Orangeburg fine sandy loam and potash	......	0.2	0.3	......	1.5	0.1	1.6
13	Houston loam	......	0.3	0.3	......	3.6	1.8	5.4
16	Houston loam and potash	......	0.2	0.5	......	2.2	2.8	5.0
19	Houston black clay	......	0.3	0.25	......	4.1	1.7	5.8
22	Houston black clay and potash	......	......	......	......	......	......	......
25	Yazoo clay	1.3	1.4	0.3	6.5	1.4	2.0	3.4
28	Yazoo clay and potash	1.3	1.4	0.7	6.5	1.4	4.3	5.7
31	Miller fine sandy loam	0.5	0.5	0.65	2.4	4.7	0.8	5.5
34	Miller fine sandy loam and potash	0.5	0.4	0.6	1.6	2.6	1.3	3.9
37	Crawford clay	0.5	0.6	0.2	3.0	7.2	1.5	8.7
40	Crawford clay and potash	0.5	0.7	0.4	3.0	8.4	3.1	11.5
43	Lufkin fine sandy loam	0.5	0.3	0.2	2.2	2.0	0.4	2.6
46	Lufkin fine sandy loam and potash	0.4	0.2	0.4	2.0	1.7	1.4	3.1

Table No. 21 shows the loss of lime and magnesia in pounds per acre. The loss of lime varies from 70 to 582 pounds per acre per year, on the average of three years. The loss of lime and magnesia is, in a general way, related to the lime soluble in strong hydrochloric acid. This is brought out in the table below.

TABLE NO. 23.

Parts Per Million of Lime and Magnesia in Percolates.

Pot Number.		Lime.							Magnesia.						
		Jan. 1, 1911, to April 1, 1911.	April 1, 1911, to June 17, 1911.	June 17, 1911, to Jan. 1, 1912.	Jan. 1, 1912, to July 1, 1912.	July 1, 1912, to Jan. 1, 1913.	Jan. 1, 1913, to July 1, 1913.	July 1, 1913, to Jan. 1, 1914.	Jan. 1, 1911, to April 1, 1911.	April 1, 1911, to June 17, 1911.	June 17, 1911, to Jan. 1, 1912.	Jan. 1, 1912, to July 1, 1912.	July 1, 1912, to Jan. 1, 1913.	Jan. 1, 1913, to July 1, 1913.	July 1, 1913, to Dec. 1, 1914.
1	Norfolk sand, 0	83	69	140	50	130	43.2	46.0	5	16	32	13	19	13.7	22.0
4	Norfolk sand and potash	79	66	145	51	266	111.2	78.0	5	19	29	10	38	22.8	21.5
7	Orangeburg fine sandy loam, 0	233	127	193	66	198	100.2	73.5	22	18	31	11	26	20.8	24.0
10	Orangeburg fine sandy loam and potash	274	147	171	71	202	147.6	97.0	34	25	32	14	29	31.1	27.5
13	Houston loam, 0	144	117	148	53	98	49.0	44.0	23	24	24	10	20	15.0	13.5
16	Houston loam and potash	158	86	126	76	145	85.6	71.0	24	25	29	17	27	17.4	19.5
19	Houston black clay, 0	203	107	198	66	208	100.6	97.0	10	12	18	9	15	8.2	20.5
22	Houston black clay and potash	189	108	136	90	97	121.8	105.5	10	11	15	7	4	10.0	19.0
25	Yazoo clay, 0	413	199	276	118	342	182.1	154.5	14	21	29	8	27	21.6	24.0
28	Yazoo clay and potash	286	102	307	134	381	222.4	196.0	15	17	30	9	29	23.5	25.5
31	Miller fine sandy loam, 0	268	170	233	32	146	74.2	66.5	51	32	38	9	15	22.8	24.5
34	Miller fine sandy loam and potash	299	232	233	89	279	170.2	90.0	49	47	50	8	56	38.7	28.5
37	Crawford clay, 0	250	150	247	91	250	151.1	138.5	17	9	19	7	13	14.5	14.5
40	Crawford clay and potash	299	162	310	100	398	245.3	192.0	17	9	25	14	17	15.4	19.0
43	Lufkin fine sandy loam, 0	111	115	137	52	122	75.2	72.5	43	31	41	14	28	32.0	22.0
46	Lufkin fine sandy loam and potash	119	117	152	75	216	119.4	87.5	45	34	49	12	57	30.1	42.0

The soils containing less than 0.7 per cent. lime soluble in acids lose from 172 to 259 pounds lime per acre per year. Those containing over 1 per cent. lime soluble in acids lose 442 to 582 pounds per acre per year. This loss would be replaced by about 500 pounds ground limestone on the first soils and 1000 pounds on the second. With the decreased percolation of soils growing cultivated crops, these soils would, of course, lose much less lime. These soils are in no case acid.

ACKNOWLEDGMENT.

Analytical and other work involved in the preparation of this Bulletin has been done by N. C. Hamner, J. B. Rather, J. B. Kelley, L. C. Ludlum, A. J. Weaver and other members of the staff.

TABLE NO. 24.

Milligrams Per Pot of Lime and Magnesia in Percolates.

Pot No.		Lime.				Per cent lime in soil.	Magnesia.			
		1911	1912	1913	Total.		1911	1912	1913	Total.
1	Norfolk sand, 0	1256	454	22	1732	0.09	204	112	7	323
4	Norfolk sand and potash	1944	1220	1151	4315	......	358	203	244	805
7	Orangeburg fine sandy loam	2575	1011	867	4453	0.11	319	156	186	659
10	Orangeburg fine sandy loam and potash	2981	865	1138	4984	......	464	162	240	866
13	Houston loam	4132	1389	835	6348	0.17	625	271	256	1152
16	Houston loam and potash	3507	1874	1326	6704	......	732	382	298	1412
19	Houston black clay	6378	2449	2056	10863	3.30	492	249	256	997
22	Houston black clay and potash	1283	500	142	1925	......	108	38	13	152
25	Yazoo clay	7935	3340	3038	14313	2.86	610	246	398	1354
28	Yazoo clay and potash	7037	3635	3504	14176	......	620	261	400	1281
31	Miller fine sandy loam	4596	982	792	6370	0.15	805	160	248	1213
34	Miller fine sandy loam and potash	3600	1649	1350	6599	......	717	250	324	1291
37	Crawford clay	8174	2971	2847	13992	1.12	597	187	281	1065
40	Crawford clay and potash	9152	3722	4440	17314	......	645	284	331	1260
43	Lufkin fine sandy loam	2556	994	649	4229	0.59	789	247	260	1296
46	Lufkin fine sandy loam and potash	2807	8748	1339	5894	......	896	377	409	1682

	Lime lost, pounds per acre.	Average per cent CaO soil and subsoil.
Norfolk sand	70	0.09
Lufkin fine sandy loam	172	0.56
Orangeburg fine sandy loam	181	0.11
Miller fine sandy loam	259	0.15
Houston loam	258	0.18
Houston black clay	442	3.85
Crawford clay	569	1.20
Yazoo clay	582	2.72

SUMMARY AND CONCLUSIONS.

1. This Bulletin contains the results of three years' experiments on the percolation of water and mineral matter through Texas soils, in 12-inch pots, under Texas conditions.
2. Uncultivated clays and loams allowed more water to percolate than uncultivated sands and sandy loams.
3. Cultivation increased percolation through the sands and sandy loams, but had little effect upon the percolation through the loams and clays.

4. Sulphate of potash increased percolation through the sandy soils but decreased percolation through the clay soils.

5. Application of manure increased percolation from the sandy soils especially. The fall application of manure was more effective than the spring application.

6. The nitrates in the water percolating from the uncultivated soils is related to a certain extent to the total nitrogen of soil and subsoil.

7. More nitrates appeared in the percolates from manure applied October 15 than from that applied March 15. On an average, 53.7 per cent. of the nitrogen was thus changed. The nitrates produced from 9 tons of manure per year were sufficient for about 20 bushels of corn.

8. An application of nitrate of soda gave an increase in the nitrates in the succeeding percolates of two of the soils, but, with the other six soils, no effect was observed until three or four weeks later.

9. Only small quantities of potash appeared in the percolates from most of the soils, even after heavy applications of potash were made. In three years, the maximum loss was 12 per cent. with the Norfolk sand, and from 0 to 4.5 per cent. with the other soils.

10. From 9.7 to 66.6 pounds per acre per year of potash were lost by percolation from the uncropped, uncultivated soils. Losses from cropped soils would, of course, be much less. The losses are to a certain extent related to the active potash of the soil.

11. Losses of phosphoric acid in the percolates was very small.

12. Losses of lime from the uncropped, uncultivated soils vary from 70 to 582 pounds per acre and is, in a general way, related to the quantity of lime soluble in strong hydrochloric acid.

The conclusions given above may be modified or supplemented by related work carried on at the same time, in which the soils were weighed, and which has not yet been digested for publication.

D T Mason

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A. B. Recknage

BORDER CUTTINGS:
A SUGGESTED DEPARTURE IN AMERICAN SILVICULTURE

BY

A. B. RECKNAGEL

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BORDER CUTTINGS—A SUGGESTED DEPARTURE IN AMERICAN SILVICULTURE

BY A. B. RECKNAGEL

(Contributed)

American forestry is frankly dependent on natural regeneration except in emergencies. To secure this we have, almost universally, adopted a selection system of cutting, which, starting with a crude diameter limit method, has evolved into a shelterwood selection method, somewhat along the lines of Gayer's "Femelschlagform." This method aims, briefly, to cut over an area now, leaving about one-third of the merchantable stand for purposes of regenerating the area naturally and to form the basis of a second cut in about 30 to 50 years. It is nearly five years since this method was inaugurated in the National Forests, and as yet the results have not been reassuring. Of course, no method of natural regeneration expects to secure a complete restocking of the area; there are always some fail places which must be restocked artificially.

But admitting that a satisfactory regeneration is secured in the 30 to 50 years following the cutting, what happens in the meanwhile? The area, with about one-third of the merchantable stand still on it, is subjected to all the injurious effects of drouth, insolation, and storm, as well as of snow, frost, fire, fungi, weeds, and insects. The larger the cutting area the more these will make themselves felt. The one-third of the stand left is not sufficient to prevent a strong drying-out of the soil by sun and wind; much of the precipitation is caught by the trees left standing, and thus does not reach the ground, while in times of drouth the larger trees rob the reproduction (seedlings) of much of the ground moisture which is the latter's due.* Similarly, windfall is increased, and the growth of weeds and sod fostered to the detriment of any tree seed which may try to germinate thereon. Snow break and frost damage is accentuated, as is also the danger of insect and fungus attacks. Finally, the danger of disastrous fires is multiplied, not only because of the unavoidable debris left after logging, but because of the large continuous areas of highly inflammable seedlings. It is probably true, also, that lightning damage, with its attendant fire menace, is increased.

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* An excellent instance of this is found near Eberswalde, Germany, where three and four year old plantations under shelter of mature trees suffered more from the great drouth of 1911 than did similar plantations standing in the open.

In Europe the history of forest management has gone through the stages of extensive selection cutting, leading to systematized shelterwood or selection methods (Schirmschlagform, Femelschlagform, Plenterschlagform), with many variations. It is highly significant that in Germany these methods, practised as they were on large areas (Grossschlagwirtschaft), proved so uniformly unsatisfactory that they were abandoned in favor of clear cutting and artificial regeneration (Kahlschlagbetrieb), which characterized German forestry in the nineteenth century. The tremendous expense and manifest drawbacks to this method (deteriorating soil and yield, insect and fungus ravages, etc.) have led the foremost German foresters back to a systematized selection system—but one based on small areas (Wirtschaft der kleinsten Fläche) in contrast to the large area management of former times—with natural regeneration and well-distributed age classes, but with stands approximately even aged.

This last requirement is the result of dearly bought experience in the old shelterwood and selection cuttings, where much of the laboriously achieved reproduction was destroyed in removing the larger trees which had been left. Can we expect better results when the time comes for a "second cutting" 30 or 50 years after the first?

In his "Grundlagen der Räumlichen Ordnung im Walde," * Professor Wagner, of Tübingen, describes a method of selection border cuttings (Blendersaumschlag) which offers a way to avoid these strong disadvantages of a "straight" selection or shelterwood cutting. In its essentials this method is a progressive selection-strip cutting from north to south, which utilizes the mature products in selection cuttings, at the same time securing natural regeneration of the forest. The strips or "borders" run east and west; they are narrow, since this is the most favorable to natural regeneration; they progress from north to south, since the closed, mature stand on the south side affords the maximum protection from drouth, wind, frost, snow, and the like without preventing the free access of precipitation to the regenerated area. The progress of the cutting and of the regeneration depends primarily on the degree to which reproduction has been secured and the needs of that reproduction. This progress of regeneration over the cutting area can be likened to the reading of a printed page, where the eye sweeps from the top to the bottom, line for line, steadily withal, yet halting occasionally until some difficult passage has been mastered.

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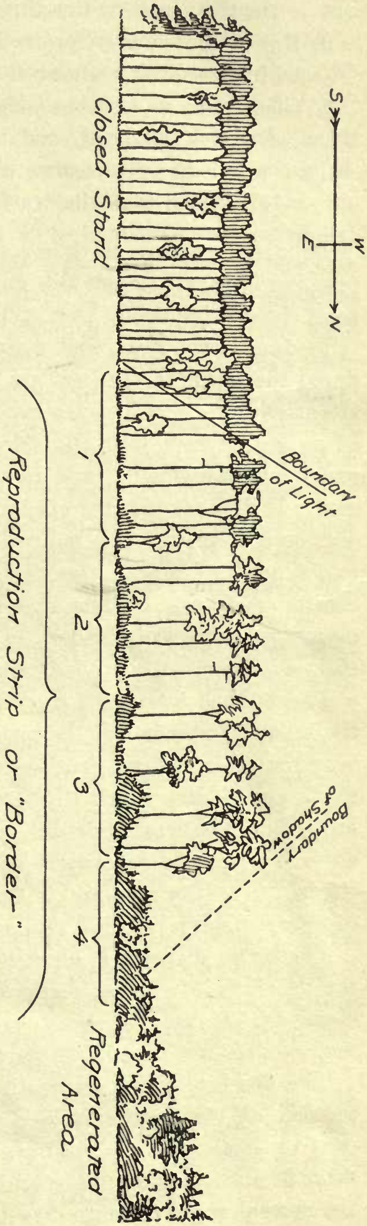
* Second edition, 1911, H. Laupp, publisher, Tübingen, Württemberg, Germany.

Is this method applicable to our conditions?

In the first place it is not chimerical as it might appear, but is based on 15 years of practical experience in Württemberg. The same basic principles hold good in America; but the method must be modified to meet our more extensive conditions. We cannot market where and what we will, but only "where" the proposition can be made attractive to some lumberman and "what" is merchantable. The purchasers of stumpage would likely object to a method of successive strips, but their objections would be tempered by the fact that they get all the merchantable material on the area instead of only two-thirds as formerly. This, of course, is also of substantial advantage to the forest owner, offsetting the expense of more rigid fire protection on an area without seed trees.



Profile of a Cutting Series in Selection Border Cuttings

Adapted from page 154, 2d edit., Wagner's 'Die Grundlagen der Räumlichen Ordnung im Walde'

The total width of each strip should usually not exceed four mature tree heights, or about five chains (330 feet), and represents all gradations from clear cutting at the outer edge to the closed stand at the inner edge. The strips are not cut clear at first (except the initial border, which allows access of light to the area to be regenerated), but are cut according to the selection system. The entire strip is composed of four parts, from the inside outward (see accompanying sketch). These are:

1. Bordering on the closed stand: cut lightly, with a view to encouraging germ-

ination of the seed. (This would usually remove one-third of the merchantable stand.)

2. Cut moderately, so that seedlings may develop. (This would usually remove two-thirds of the original merchantable stand.)
3. Cut all but a few "protectors," so that seedlings may be prepared for standing without an overhead shelter.
4. Clear cut; no overhead shelter, but protection from mature trees on strips 3, 2, 1, and the main stand adjoining these. (This would usually remove everything merchantable—*i. e.,* generally all over 6 to 12 inches D. B. H.)

Thus the cutting advances gradually into the closed stand. This progress is usually about two chains per annum, but should be varied to meet the specific conditions. The method aims to utilize the seed which is produced each year, and thus in years when little or no seed is produced the selection cuttings are not pushed on into the closed stand, but attention is centered on the seedlings already secured. At the prospect of an ample seed year the selection cuttings are pushed farther than usual into the closed stand in order to utilize the larger production of seed. In this manner the effects of a bountiful seed crop can be extended over several years. The method is essentially flexible in its adaptability to the needs of various species and sites, though it is primarily suited to coniferous forests. Thus in regenerating light demanding species the clean-cut strip can be wider; in tolerant species not so wide. Again, on steep slopes or easily eroded soils the clean-cut strip can be kept narrow.

The method admits of modification very easily and brings into play the keenest judgment of the trained forester. For example, it allows the very desirable natural creation of mixed stands, through the variety of shade and shelter which it offers. This can be encouraged by removing large, heavy-crowned tolerant species first, then those of medium tolerance, leaving the intolerant species (provided they be wind-firm) to the last to scatter seed and to furnish protection to the seedlings (mostly of tolerant species) below and around them.

The brush disposal is identical with that now in vogue; the decay of the debris is, of course, accelerated because of complete exposure to the elements. In general, brush scattering is recommended where the fire menace does not necessitate partial or complete burning.

The absolute north to south progress of cutting is, of course, only possible on comparatively level ground (slopes of 5 degrees equal 9 per cent or less). In mountainous country the direction of the cuttings must be such that the material is always removed down hill. Therefore, the normal north to south direction need not be changed on slopes facing the east, southeast, south, southwest, or west, but on the northwest, north, and northeast slopes the borders should run up and down the slope, progressing in a southwest, west, and southeast direction respectively. This change from the customary north to south direction will have no ill effect silviculturally, since northwest, north, and northeast slopes are *ipso facto* protected from undue sun, and therefore are usually moist enough to encourage seedling growth.

Logging is made easy in this method if, as far as possible, the main skidding trails or skid roads are laid out running north and south between the cutting series. These will also serve as boundaries between the areas, and on occasion may be kept as permanent roads or as fire lines. In logging all material is moved away from the regenerated parts; hence the method minimizes injury to young growth during removal of the mature crop; the mature trees left as "protectors" are removed while the reproduction is still in the seedling stage, when damage is negligible, whereas in a later stage it is often exceedingly damaging to the laboriously achieved regeneration and may destroy it entirely.

Any fail places which persist after ample opportunity has been given for natural regeneration must be seeded or planted. This measure is inevitable in any method of natural regeneration; it is minimized in the "border" method, because of the favorable position in which the stand is placed for natural reproduction, and the prevention of injury to the established young growth in the "second cut."

The final remaining strip should be regenerated by a groupwise selection cutting unless, of course, it joins on to a closed stand of seed-bearing age.

As for the distance between the cutting series or points of attack, this depends on the time within which the entire area must be regenerated and the size of the area. The quicker an area must be cut over and the smaller it is, the closer together must the cutting series be. Conversely, the slower the area can be cut over and the larger it is, the farther apart can the cutting series be; but in order to secure the manifest advantages of a relatively even-aged stand—*i, e.,* ordinarily one with no greater divergence than 30 years in the age of its component members—the cutting series should seldom be more than 60 chains (three-quarters of a mile) apart. This is based on an annual progression of two chains, a factor which must be varied as local experience dictates.

Assuming a unit area and different periods in which it is to be cut over—*i. e.,* regenerated—we get the following table of factors. (Areas to be regenerated in a single cutting extending over less than four or five years, of course, do not come under this method:)

Period of cutting—years.	Distance between each cutting series—chains.	Average amount per cent total stand to be cut each year.
4	8	25
5	10	20
6	12	16⅔
8	16	12½
10	20	10
20	40	5
30	60	3⅓
40	80	2½

This may be shown diagrammatically as follows: Assuming as unit of area a square section (640 acres), with an average stand of 5,000 feet, board measure, per acre, a total of 3,200,000 feet for the whole section.

In its application this method presupposes a careful division of the cutting area into types and the notation of the areas of burns, blanks, previous cuttings, young growth, and the like. The average stand per acre must also be determined for each type. All these data and more are already required in the timber estimate and forest description of the Forest Service and in the reconnaissance estimates, maps, and descriptions as well.

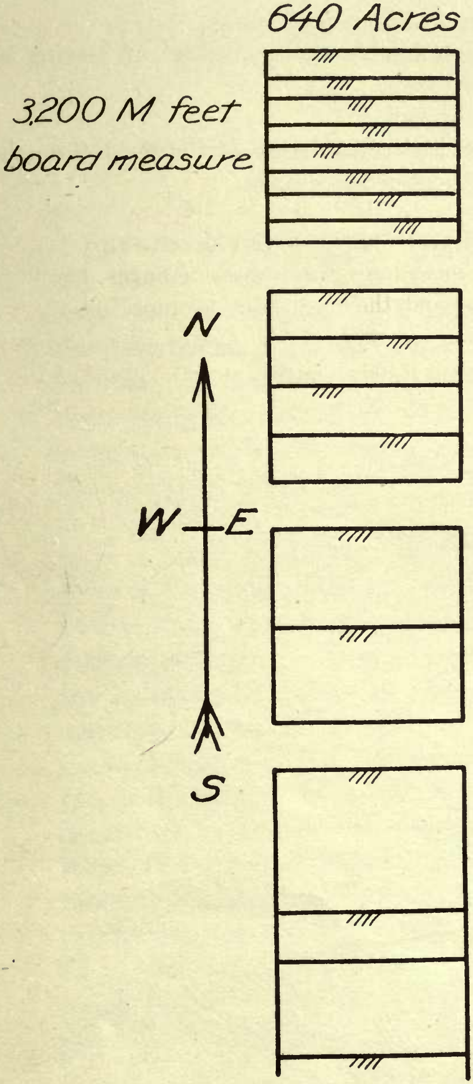
In this method area and volume check each other—*e. g.,* knowing the volume to be cut each year the requisite area can be worked over, and conversely. The method facilitates and systematizes supervision and administration. The marking of the trees in the selection cutting, the supervision of the logging, and the inspection of the resultant regeneration are made simple in so definitely bounded an area.

The final result will be a segregation of the age classes, each in their proportional area, with even-aged stands instead of the all-aged, or at best several-storied forest, which results from the usual shelterwood and selection cuttings. Thus the method leads over to a regulation of yield by area according to age classes, which has come to be considered the "ultima ratio" of systematic forest management.

As to the increased menace—*i. e.,* that fire may destroy the entire reproduction without leaving any seed trees present to restock the area—it may be repeated that the increased yield will allow of more extensive methods of fire protection, and that in general the practice of forestry presupposes efficient fire protection, especially of young growth.

The practical application of this method in America depends on the accessibility of all parts of the tract to be logged, which means a well-developed system of roads or other method of transportation. It will meet with the best success on good fresh soil and with coniferous species. In regenerating hardwoods such elaborate protection from storm and drought is seldom necessary.

Since it is not intended for use in regenerating areas that are to be cut over in less than four or five years, it, unfortunately, is not applicable to the majority of Forest Service timber sales, unless there be assurance that a given area of timber will afford a continuous cut for a longer period than that, and that the mills to which the logs go constitute a steady, reliable demand for all the timber cut in the period of regeneration.



Five-year cutting period.
Eight cutting series.
Each one-eighth mile apart.
Each cut per year, 80 M.
Total per year, 640 M = 20 %.

Ten-year cutting period.
Four cutting series.
Each one-quarter mile apart.
Each cut per year, 80 M.
Total per year, 320 M = 10 %.

Twenty-year cutting period.
Two cutting series.
Each half mile apart.
Each cut per year, 80 M.
Total per year, 160 M = 5 %.

Thirty-year cutting period.
One and one-third cutting series.
Each three-quarters mile apart.
Each cut per year, 80 M.
Total (per 640 acres) per year, 106 M = 3⅓ %.

Unfortunately, this combination of conditions is still rare in America. Occasional opportunities, however, are already at hand—for example, in some of the spruce forests of the north woods. These opportunities will continue to multiply, and the forester should therefore bear in mind a method which offers:

1. Natural regeneration with a minimum of loss.
2. Utilization of all the merchantable timber instead of leaving a large percentage as seed trees.
3. Easy logging and brush disposal.
4. Simplified administration; easier regulation of the yield through the systematic development of age classes.

Black Forest, Germany.

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THE INDICATOR SIGNIFICANCE OF NATIVE VEGETATION IN THE DETERMINATION OF FOREST SITES

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Phytogeographers have long recognized certain variations in the native vegetation of given regions, while phytoecologists have only recently made notable advances in the correlation of the vegetation with the climatic and edaphic factors of the habitat. Within the last decade the physiological ecologist has been doing some excellent work on the correlation of the native vegetation with the crop-producing potentialities of the land, the results of which have a very practical application in present-day agriculture.

As a result of detailed studies in the Great Plains region of eastern Colorado, Shantz[1] concludes that the character of the native plant cover can be used as a reliable indicator of the conditions favorable or unfavorable for crop production, provided the relation between the vegetation and the environment is correctly interpreted. The correlations which exist in the Great Plains between the different types of vegetation and the physical characteristics of the corresponding types of land are described in detail. Shantz discusses at length the ways in which the native vegetation may be used in that region to determine the adaptability of the land for dry farming. The crop production on wire-grass land during favorable years is almost as good as on short-grass land and during normal and dry years much better crops are produced on wire-grass than on short-grass land. Using the native vegetation as an indicator of the capabilities of crop production, the type of land that is characterized by the wire-grass association is classed as the most valuable agricultural land in eastern Colorado. That type of short-grass land which bears a considerable growth of wire-grass or *Psoralea* is classed with or very close to the wire-grass association land, since the presence of these plants indicate conditions intermediate between those of the typical wire-grass association and those indicated by the typical grama—buffalo-grass association. On new land where crops have not yet been produced, the character, growth, and condition of the native vegetation are the best possible indicators of crop production, either positive or negative, since plant growth is the ultimate criterion of the suitability of the physical environment.

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[1] Shantz, H. L. Native Vegetation as an Indicator of the Capabilities of Land for Crop Production in the Great Plains Area, U. S. Dept. of Agri., Bur. of Plant Ind. Bul. 201, 100 pp. 1911.

Kearney and others[2] have gone still farther in the scientific study of native vegetation from the indicator point of view in suggesting the possibility of correlating the distribution of the vegetation with the physical and chemical properties of the soil and the utilization of such a correlation in the classification of the agricultural potentialities of the land. The investigations in the Great Basin of central Utah were directed toward the solution of the problems of what types of vegetation indicate conditions of soil moisture favorable or unfavorable to dry farming and what types indicate the presence or absence of alkaline salts in sufficient quantities to injure cultivated crops. The results of the studies in Tooele Valley show that the different types of native vegetation indicate the conditions of soil moisture and alkalinity of the land on which they are found and consequently provide a basis for estimating its potentialities for crop production. A good stand and growth of sagebrush (*Artemisia tridentata*) indicates land that is well adapted to both dry and irrigation farming. Where the stand of sagebrush is open and the growth poor the good soil is usually too shallow for profitable crop production, at least without irrigation. Dry farming is precarious on land covered by the Kochia (*Kochia*

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[2] Kearney, T. H., Briggs, L. J., Shantz, H. L., McLane, J. W. and Piemeisel, R. L. Indicator Significance of Vegetation in Tooele Valley, Utah. Journal of Agricultural Research **1**: 365–417. 1914.

vestita) and shadscale (*Atriplex confertifolia*) associations, due to the shallowness of the alkali-free soil. Land occupied by the greasewood—shad-scale (*Sarcobatus vermiculatus* and *Atriplex confertifolia*) association is unsuitable for dry farming, but will produce good crops under irrigation.

The work on the correlation of the native vegetation with the crop-producing capabilities of the land has frequently suggested to the writer the possibility of utilizing the native vegetation in the determination of forest sites. In forestry, site is defined as an area considered as to its physical factors with reference to forest producing power; the combination of the climatic and edaphic conditions of an area or the forest habitat. For purposes of comparison the various sites are commonly segregated into site classes. Site class is a designation of the relative productive capacity or quality of different sites with reference to the species employed; the volume or the height produced at a given age being commonly used as the standard for classification. In the United States frequently only three classes are differentiated, designated by Roman numerals, quality I representing the most productive site class.

In a perusal of forestry literature one is impressed with the apparent fact that until only recently has much attention been given to the native vegetation, aside from the forest trees themselves, in the classification and segregation of forest sites. The majority of the references to the variation in the native herbaceous vegetation on different forest sites have been made incident to the describing of different sites or in characterizing their ground cover instead of from the indicator point of view.

The rather radical work of Cajander[3] must be cited as an exception to this statement. As a result of investigations of herbaceous and forest associations conducted in Finland, Germany, Austria-Hungary, Switzerland, Northern Russia and Siberia, Cajander concludes that, since no forester is in a position to determine definitely the limits of a dry or a moist soil, the difference in forest types must be based upon the character of the living ground cover as the clearest indicator of the site. Although Cajander admits that in virgin forests the composition of the forest itself correlated with the living ground cover is the best criterion of the physical conditions of growth, he further maintains that in forests which are under the influence of man the living ground cover alone may serve as a criterion and indicator of the physical conditions of the site. The latter statement is at variance with American ideas because of the failure to correlate the living ground cover with the different physical conditions of growth and the failure to appreciate the effect of the varying density of the forest cover on the living ground cover.

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[3] Cajander, A. K. Über Waldtypen, Helsingfors, 1909, Fennia 28, No. 2, 175 pp. Reviewed by Raphael Zon in Proc. Soc. Amer. Foresters **9**: 119–125. 1914.

In pointing out the value of the native vegetation as a criterion of the potential productivity of land and its application to modern land classification, Pearson[4] maintains that a forest may be regarded as the aggregate effect or the summation of the physical conditions obtaining on the site on which it grows and that the consideration of the potentiality of the land need not be confined to the trees. Shrubs, herbs and even the lower forms of plant life may be correlated effectively with the physical factors of the site and also with the tree growth. Pearson concludes that the simpler and more reliable basis for the determination of the adaptability of the site for different crops consists in the use of characteristic forms of the native vegetation as indicators of the physical conditions of the site.

Mason[5] reports the abundance of huckleberry (*Vaccinium scoparium*) on the poorer lodgepole pine (*Pinus contorta*) sites of the Rocky Mountains. Alder (*Alnus tenuifolia*) and willow frequently occur as underbrush in moist situations of the same forest type.

Clements[6] in discussing the vegetative succession on burned-over areas in the lodgepole pine forest of the central Rocky

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[4] Pearson, G. A. What is the Proper Basis for the Classification of Forest Land into Types? Proc. Soc. Amer. Foresters **8**: 79–84. 1913.

[5] Mason, D. T. The Life History of Lodgepole Pine in the Rocky Mountains. U. S. Dept. of Agri. Bul. 154, pp. 11–12. 1915.

[6] Clements, F. E. The Life History of Lodgepole Burn Forests, U. S. Dept. of Agri., Forest Service Bul. 79, 56 pp. 1910.

Mountains, points out differences in the density and composition of the living ground cover varying with the favorableness or unfavorableness of the different lodgepole pine sites. The vegetative succession occurring on the burns during the course of the reëstablishment of the original forest cover shows, in an interesting way, the superseding of the xerophytically-inclined vegetation by vegetation possessing more mesophytic tendencies, until, as the site becomes more and more mesophytic, the original forest cover is eventually established. The relative mesophytism of the site at each of the more or less distinct stages of the succession is indicated by the native vegetation occurring on the site at that particular time. It is true, however, that the vegetation of any of the unstable stages of the succession cannot be regarded as being indicative of the latent potentiality of the site. The ultimate climax stage of the succession must have been reached before much importance can be attached to the indicator significance of the native vegetation in the determination of site, especially from the standpoint of the forester.

Zon[7] in describing the forest types in which balsam fir (*Abies balsamea*) occurs, states that sphagnum and other mosses are the principal species which comprise the living ground cover of the swamp type. Fern moss replaces sphagnum as the predominating ground cover of the flat type. Ferns and certain flowering plants become the conspicuous herbaceous plants of the hardwood slope type in which balsam fir is reported as attaining its best individual development although the best stand development occurs in the flat type. The descriptions of the forest types are supported by lists which show the relative proportion of the different species and the character of the vegetation comprising the living ground cover of the swamp, flat, and hardwood slope types.

Hole and Singh[8] in studying the soil types and native vegetation of the sal forests in the vicinity of the Forest Research

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[7] Zon, Raphael. Balsam Fir. U. S. Dept. of Agri. Bul. 55, pp. 4–7. 1914.

[8] Hole, R. S. and Singh, Puran. Oecology of Sal (*Shorea robusta*); Part I, Soil composition, soil-moisture, soil-aeration. Indian Forest Records, Vol. V, Part IV, pp. 13–14. 1914.

Institute, Dehra Dun, India, consider three principal soil types, each of which is characterized by distinct types of vegetation. The poorer soils, containing a large percentage of sand and a relatively small amount of silt, are frequently shallow, with gravel and boulders below. These soils are essentially dry and bear a dry forest with *Acacia catechu* and *Dalbergia sissoo* prominent, or grassland with *Saccharum munja* dominant. The well-aerated deep loams are covered with a sal forest or grassland with *Saccharum narenga* (often mixed with *Anthistiria gigantea* subsp. *arundinacea*) dominant. The poorly-aerated deep loams, differing from the well-aerated soils in containing more clay and silt, in actually being heavier, or in having the water-table nearer the surface, are characterized by a moist forest with *Betula frondosa, Stereospermum suaveolens, Terminalia, Cedrela toona* and others, or grassland with *Erianthus ravennae* (often mixed with *Anthistiria gigantea* subsp. *villosa*) dominant.

More recent work by the same investigators[9] indicates that the dominant grasses on an area are excellent indicators of the soil conditions. In northern India, where *Saccharum narenga* and *Anthistiria gigantea* subsp. *arundinacea* tend to be dominant, the soil moisture and aeration are suitable for the best development of sal and the moist type of sal forest prevails, in the shaded parts of which the reproduction suffers from poor soil aeration. Such grasses as *Saccharum munja, Saccharum spontaneum, Eragrostis cynosuroides, Imperata arundinacea, Vetiveria zizanioides, Andropogon contortus* and *Ischaemum angustifolium* usually indicate a soil too dry, or too heavy, for the best development of sal and such forests as occur are of the dry sal type.

Pearson[10], in discussing the effect of a cover of aspen (*Populus tremuloides*) upon the establishment of Douglas fir (*Pseudotsuga taxifolia*), has made a very interesting comparison of two different sites which occur at the transition between the Douglas fir and western yellow pine (*Pinus ponderosa*) types at an elevation of 8700 feet on the San Francisco Mountains in northern Arizona. Both sites had the same exposure but one was aspen-covered and the other was in the open. After making detailed studies of the physical factors of the two adjacent sites, the survival and development of Douglas fir planted on both sites and the correlation of the native vegetation occurring on the sites the conclusion was drawn that the open sites, due to their greater severity, should doubtless be reforested with western yellow pine (*Pinus ponderosa*) while the aspen-covered areas should be planted with Douglas fir. The aspen thickets supported a luxuriant growth of broad-leaved mesophytic herbaceous plants, such as *Frasera scabra*, *Pteridium aquilinum* and *Verbascum thapsus*, while grasses (*Muhlenbergia gracilis*, *Festuca arizonica*, *Festuca pseudovina*, and *Bromus polyanthus*) predominated in the openings. The growth of all herbaceous plants was invariably more luxuriant under the aspen than in the open.

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[9] Hole, R. S. and Singh, Puran. Oecology of Sal (*Shorea robusta*); Part II, Seedling Reproduction in Natural Forests and its Improvement. Indian Forest Records, Vol. V, Part IV, pp. 83–84. 1916.

[10] Pearson, G. A. The Rôle of Aspen in the Reforestation of Mountain Burns in Arizona and New Mexico. The Plant World **17**: 249–260. 1914.

Shreve[11] reports a rather marked variation in the distribution of the vegetation occurring in a forest of *Pinus arizonica* on the Santa Catalina Mountains in southern Arizona. Throughout the pine forest are to be found a large number of herbaceous perennials, the greater majority of which accompany the closed stands of pine. The occurrence of another large group of plants is confined to the near proximity of streams and stream-courses. In the dense shade of the evergreen-oak woodland *Pteris aquilina* is reported as being common, and it again becomes common in the pine forest above 7500 feet, but is infrequent in the lower portion of the forest region. *Alnus acuminata*, *Acer interius*, and *Quercus submollis* become frequent along streams at about 6800 feet. Herbaceous plants are reported as being found in increasing numbers at or near the banks of streams between 6000 and 7400 feet, among which may be mentioned *Juncus arizonicus*, *Aquilegia chrysantha*, *Thalictrum fendleri* var. *wrightii*, *Scrophularia* sp., *Trifolium pinetorum*, *Fragaria ovalis*, *Poten-*

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[11] Shreve, Forrest. The Vegetation of a Desert Mountain Range as Conditioned by Climatic Factors, Pub. 217, Carnegie Inst. Wash. 112 pp. 1915.

tilla thurberi, Hypericum formosum, Lobelia gruina, Agrimonia brittoniana var. *occidentalis, Gaura suffulta,* and *Tagetes lemmoni.*

Weaver[12] has recorded the variation in the vegetative undergrowth with a change of the site in the cedar (*Thuja plicata*) forest on the Thatuna Hills in southeastern Washington. Near the streams the forest floor is covered with *Athyrium cyclosorum* which gives way farther back to a rather dense growth of *Rubus parviflorus, Vagnera amplexicaulis, Tiarella unifoliata, Trillium ovatum, Clintonia uniflora, Disporum majus, Pyrola* sp., *Actaea spicata arguta,* and *Coptis occidentalis, Viola* sp., *Streptopus amplexifolius,* and *Phegopteris dryopteris.* These together with the cedar seedlings comprise the characteristic undergrowth, while farther up the slope there is almost no living ground cover.

Fuller[13] notes the relation between the mesophytism of a site and the undergrowth in some comparatively undisturbed beech-maple forests about 45 miles southeast of Chicago, when he states that the lower evaporation in the ravine may be a sufficient explanation for the presence upon its slopes of a much greater abundance of such delicate forms as *Dicentra canadensis, D. cucullaria, Impatiens biflora,* and *Asplenium angustifolium.*

Peters,[14] as a result of observations made in Northampton County, Pennsylvania as early as 1806, calls attention to the fact that the timber alone is not always an invariable indicator of the capabilities of the land. Hemlock (*Tsuga canadensis*), white pine (*Pinus strobus*), and pitch pine (*Pinus rigida*) were reported as occurring on deep, fertile loams as well as on the thinnest, sterile, sandy soils. It is readily seen that the vegetation must be properly correlated with its habitat and the relation between vegetation and environment must be correctly interpreted.

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[12] Weaver, John E. Evaporation and Plant Succession in Southeastern Washington and Adjacent Idaho. The Plant World **17**: 273-294. 1914.

[13] Fuller, George D. Evaporation and the Stratification of Vegetation. Bot. Gaz. **54**: 424–426. 1912.

[14] Peters, Richard. The Departure of Southern Pine Timber and Proof of the Tendency in Nature to a Change in Products on the Same Soil. Memoirs of the Philadelphia Society for Promoting Agriculture, containing communications on various subjects in husbandry, and rural affairs, Vol. I, page 30, Philadelphia. 1815. From notes on plant succession abstracted and furnished by Dr. H. L. Shantz.

It should be clearly recognized that the use of native vegetation as an indicator of forest sites is not without certain limitations. The use of native shrubby, and particularly herbaceous, vegetation as forest site indicators is not exactly comparable to using native open-land vegetation as an indicator of the crop productivity of an open-land site. In the case of the forest site the presence or absence of an over-wood must be recognized as an influential factor. The use of shrubby and herbaceous vegetation as indicators of forest sites encounters more obstacles in the dense Douglas fir, lodgepole pine, and Engelmann spruce (*Picea engelmanni*) forests than in the comparatively open western yellow pine forests. In the dense forests herbaceous plants are rather scarce except in partial openings or where the stand is below its normal density. The vegetation of the denser forests also varies in its composition from place to place, not only according to the favorableness of the site, but also with the density of the crown cover and consequently the amount of shade in the forest. The floor of the fir, spruce and lodgepole pine forests is more heavily and continuously shaded than that of the densest stands of western yellow pine. The factor of shade is of great importance in conditioning the character of the shrubby and herbaceous vegetation of dense forests.

While engaged in the remeasurement of a set of permanent sample plots aggregating 26.4 acres on the San Mateo Division of the Datil National Forest in west central New Mexico in the summer of 1915 the writer was impressed with the variation in the vegetation occurring on the different western yellow pine sites. The San Mateo Mountain range extends in a general north and south direction and rises to a height of 9500 to 10,500 feet above sea level. The north and west portions of the mountains slope quite gradually to the adjacent rolling plains. The east and south portions of the range break off quite abruptly to the plains. The majority of the steeper east and south aspects bear such species as *Juniperus monosperma, J. pachyphloea, Pinus edulis, Quercus chry-*

solepis, *Q. undulata*, and *Cercocarpus breviflorus*, while western yellow pine predominates on the more gradual slopes which are more retentive of soil moisture. In the more protected and more moist situations, such as cañon bottoms and north slopes at the higher elevations, *Pseudotsuga taxifolia*, *Abies concolor*, *Pinus flexilis*, *Picea engelmanni*, *P. parryana*, and *Populus tremuloides* are found. Western yellow pine occupies the more gradual slopes and situations at the intermediate elevations. A rather erratic altitudinal distribution of the species is evident in the San Mateo Mountains. At the elevation of the plots, which is approximately 8000 feet above sea level the cañon bottoms, north slopes and lower south slopes are occupied by an almost pure stand of western yellow pine which is typical of the San Mateo Mountains, while a belt of the more xerophytic species is frequently found on the more exposed upper south slopes above the western yellow pine.

The plots were established in 1910 with the principal object of determining the rate of growth and decadence of western yellow pine in this locality. They are located in the cañon bottoms and on the slopes, the gradients of which vary from 3 to 50%. Prior to the establishment of the plots the area had been cut-over, removing many of the mature and over-mature trees and a large proportion of the merchantable material. A modified selection system of cutting to a variable diameter limit was followed when the timber was marked. Occasionally large merchantable trees were reserved as seed or fire insurance trees or to maintain the general continuity of the forest cover. When the plots were established in 1910, the diameters and total heights of all trees 3.6 inches or more in diameter at 4.5 feet above the ground were measured. Each tree was described, especially with reference to its vigor, health or decadence, its crown class and all diseases, defects or abnormalities were noted. The plots were remeasured and examined in 1915, thus giving their history for the intervening five-year period.

Two well-recognized forms of *Pinus ponderosa* are distinguished, "black jack" and "yellow pine," based on age, rate of growth, and the resulting color of the bark. The term "black jack" applies to the young, vigorous trees under 125 to 150 years old which are characterized by a dark, almost black, or dark brown, narrow-furrowed bark. The "yellow pine" form comprises the older trees which are characterized by a yellowish or reddish brown, widely furrowed bark. A marked difference occurs between the form and volume of "black jacks" and "yellow pines." The average "black jack" has a greater taper, a more rapid rate of growth and approximately 10% smaller cubic volume than the average "yellow pine" of the same diameter and height, which are the main reasons for the segregation of "black jack" and "yellow pine" by technical foresters.

Two distinct western yellow pine sites were very readily recognized through apparent differences in the composition, density, rate of growth, and vigor of the forest and the corresponding differences in the shrubby and herbaceous vegetation. The soil of Site I, which occupies the cañon bottoms and the protected north slopes, is a deep gravelly clay loam containing considerable amounts of organic matter and is consequently comparatively retentive of soil moisture. Site II, which as a shallow well-drained gravelly soil containing little organic matter, is found on the ridge-tops and exposed south slopes. At the time of the 1915 examination the two sites were segregated and each was mapped separately. Approximately 16.0 acres were classed as Site I, while 10.4 acres fell into Site II.

The growth data were segregated in separate compilations for each site and for the two forms of western yellow pine.[15] The total volume growth or increment of all trees measured was computed for the five-year period. The total volumes were computed by applying a volume table based on diameter and total height to the dimensions of each tree at each time of measurement. The difference between the total volumes at each time of measurement represents the periodic increment and the average volume growth per year during the period considered is the periodic annual increment. Table 1 shows the increment of both forms of western yellow pine for Sites I and II. The data are significant in that they indicate the relative productivity of the two sites and the variability of the increment depending on the kind and amount of growing stock. The data given in table 1 represent the net increment since the volumes of all trees which died during the quinquennium were considered as negative increment and the volumes of all trees growing into the 4-inch class as positive increment. The fact that the plots were cut-over in 1910 under Forest Service regulations accounts for the relatively small amount of merchantable growing stock. The abundance of poles from 4 to 10 inches in diameter breast high which were left on the area accounts for the proportionately greater cubic volume of the growing stock. Since a number of trees grew into the merchantable class during

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[15] The writer is indebted to Forest Examiners H. B. Wales and J. W. Stokes for assistance rendered in the collection and compilation of the growth data presented in this paper.

TABLE 1

Increment data for 26.4 acres of typical western yellow pine in the San Mateo Mountains of west central New Mexico, based on five years' growth

	TOTAL MERCHANTABLE VOLUME*		MERCHANTABLE INCREMENT, 1910–1915			TOTAL CUBIC VOLUME†		CUBIC INCREMENT, 1910–1915		
	1910	1915	Periodic	Periodic annual	Annual, per acre	1910	1915	Periodic	Periodic annual	Annual, per acre
	feet B. M.	*feet B. M.*	*feet B. M.*	*feet B. M.*	*feet B. M.*	*cu. ft.*	*cu. ft.*	*cu. ft.*	*cu. ft.*	*cu. ft.*
Site I										
"Black Jack"....	16,720	22,700	5,980	1,196	75	9,723.4	10,872.3	1,148.9	229.8	14.4
"Yellow Pine"..	22,250	26,690	4,440	888	55	4,872.5	5,730.7	858.2	171.6	10.7
Total for species...	38,970	49,390	10,420	2,084	130	14,595.9	16,603.0	2,007.1	401.4	25.1
Site II										
"Black Jack"....	3,110	3,720	610	122	12	2,955.5	3,147.1	191.6	38.3	3.7
"Yellow Pine"...	8,040	10,450	2,410	482	46	2,642.6	3,244.7	602.1	120.4	11.6
Total for species...	11,150	14,170	3,020	604	58	5,598.1	6,391.8	793.7	158.7	15.3

* Includes the volumes in feet, board measure, of all western yellow pine trees 12 inches and over in diameter breast high.

† Includes the volumes in cubic feet of all western yellow pine trees 3.6 inches and over in diameter breast high.

the quinquennium and are included for the first time in the 1915 board-measure computations, the annual increment per acre as shown in board feet is perhaps somewhat greater than the mean annual increment would be for a longer period. The annual increment per acre in cubic feet is therefore considered as a better criterion of the relative productivity of each site. It is noteworthy that Site I produced 25.1 cubic feet per acre per year as against 15.3 cubic feet for Site II or, in other words Site I produced a cubic volume of 64% more than Site II during the same five-year period.

It is also interesting to compare the average breast high diameter growth of both forms of western yellow pine on the two sites. "Black jack" averaged 0.85 inch on Site I while the diameter growth of this form on Site II was only 0.71 inch. The breast high diameter growth of "yellow pine" on Site I averaged 0.75 inch, while on Site II it averaged only 0.54 inch. The mean diameter growth for the species as a whole amounted to 0.83 inch on Site I and 0.68 inch on Site II.

During the course of the compilation of the pertinent data presented above an opportunity was offered to compare the average increment per tree of the different crown classes. All of the trees on the permanent sample plots were classified according to their dominance or relative position in the crown cover, into the following crown classes:

X = *Isolated:* Trees growing in the open which do not form a contiguous part of the regular forest canopy.

D = *Dominant:* Trees with crowns extending above the general level of the forest canopy and receiving full light from above and partly from the side; larger than the average trees in the stand, and with crowns well-developed but possibly somewhat crowded.

C = *Codominant:* Trees with crowns forming the general level of the forest canopy and receiving full light from above but comparatively little from the sides; usually with medium-sized crowns more or less crowded on the sides.

I = *Intermediate:* Trees with crowns below, but still extending into the general level of the forest canopy, receiving a little direct light from above but none from the sides, usually with small crowns considerably crowded on the sides.

S = *Suppressed:* Trees with crowns below the general level of the forest canopy and receiving no direct light either from above or from the sides; usually with small, poorly developed crowns.

Table 2 shows the average increment per tree for the different crown classes on Sites I and II, only those trees being included which were living and were measured in 1910 and 1915. The greater apparent increment of the dominant crown class might be explained by the fact that in the X class a greater amount of limb-wood is produced, while in the dominant class, due to their relative position in the forest, there is a stimulation in the production of body-wood which is the portion of the tree measured to determine the increment. When the individual trees, the component parts of an aggregate stand, are given separate consideration it is evident that not only the effects of the physical site are revealed in the increment but also the effects of the individual's associates, especially their influence on the amount of light the individual receives or the amount of growing space available for its use. Although the average increment per tree varies directly with the favorableness of the conditions of the site, the writer does not wish to leave the impression that crown form may be regarded as an expression of site quality.

TABLE 2

Periodic cubic increment of western yellow pine segregated by crown classes for Sites I and II

CROWN CLASS	SITE I			SITE II			COMPARATIVE INCREMENT OF SITE II WITH SITE I
	Basis	Total periodic increment	Periodic increment per tree	Basis	Total periodic increment	Periodic increment per tree	
	no. of trees	*cu. ft.*	*cu. ft.*	*no. of trees*	*cu. ft.*	*cu. ft.*	*per cent*
X	230	622.3	2.70	204	314.1	1.54	57
D	168	617.8	3.68	87	184.4	2.12	57
C	411	721.4	1.75	247	268.9	1.08	61
I	119	69.9	.58	74	29.5	.39	67
S	14	4.4	.31	5	1.2	.24	77

It is true that crown form reflects the growing conditions as determined by competition but competition cannot be regarded as a site factor.

The differences in the native vegetation on the two different sites were so apparent that the writer immediately conceived the idea that it could be correlated with increment and used as an additional criterion in the determination of the productivity of a given forest site.

The vegetation on a number of 5 by 10-foot quadrats was listed in addition to that on the regular permanent reproduction plots of the same size, which were instituted with the primary object of studying the establishment of natural reproduction on the cut-over areas. Although the plots had been cut-over in 1910, the logging operation which was conducted under Forest Service regulations did not destroy the continuity of the forest canopy sufficiently to noticeably interfere with the stabilized climax vegetation since the virgin western yellow pine forest was originally comparatively open and park-like. The vegetation which was found on these list quadrats is systematically summarized in table 3, showing for the cañon bottoms, the north slopes, south slopes and ridge tops the percentage of the quadrats on which each species was found. The arrangement of the families is essentially an adaptation of Engler and Prantl's "Die Natürlichen Pflanzenfamilien" as used in the United States National Herbarium, which aims to indicate something of the natural developmental relationships of the families by proceeding from the simpler to the more complex. The writer desires to express his indebtedness to Prof. J. J. Thornber of the University of Arizona and Grazing Examiner R. R. Hill of the United States Forest Service for determining numerous plants and for verifying the list. A perusal of the list shows marked differences in the individuality of the vegetation of the two sites. Site I is shown to produce such typical mesophytes as *Mnium* sp., *Agrostis hiemalis, Bromus polyanthus, Muhlenbergia wrightii, Populus tremuloides, Arenaria confusa, Cerastium longipedunculatum, Silene laciniata, Aquilegia chrysantha, Thalictrum wrightii, Draba helleriana, Potentilla atrorubens, P. crinita, Rosa fendleri,*

TABLE 3

Systematic summary of vegetation on fifty-three list quadrats taken at random on the San Mateo Division of the Datil National Forest, New Mexico

	PER CENT OF QUADRATS ON WHICH SPECIES OCCUR					
	Cañon bottom (12 quadrats)	North slope (13 quadrats)	Total site I (25 quadrats)	South slope (23 quadrats)	Ridge top (5 quadrats)	Total site II (28 quadrats)
BRYACEAE						
Mnium sp.	8	15	12	0	0	0
POACEAE						
Agropyron tenerum Vasey	8	0	4	0	0	0
Agrostis hiemalis (Walt.) B. S. P.	25	0	12	0	0	0
Blepharoneuron tricholepis (Torr.) Nash	17	0	8	56	20	50
Bromus polyanthus Shear	8	0	4	0	0	0
Bromus porteri (Coult.) Nash	50	69	60	30	0	25
Festuca arizonica Vasey	17	15	16	0	20	4
Koeleria cristata (L.) Pers.	42	69	56	74	100	64
Muhlenbergia gracilis (H. B. K.) Trin.	33	54	44	65	40	61
Muhlenbergia wrightii Vasey	8	0	4	0	0	0
Poa rupicola Nash	0	0	0	39	0	32
Sitanion brevifolium J. G. Smith	17	31	24	17	80	29
Sporobolus ramulosus (H. B. K.) Kunth	17	15	16	13	0	11
CYPERACEAE						
Cyperus fendlerianus Boeckel	17	23	20	61	20	54
COMMELINACEAE						
Commelina dianthifolia Delile	0	0	0	0	20	4
LILIACEAE						
Yucca sp.	0	0	0	4	0	4
ORCHIDACEAE						
Achroanthes montana (Rothr.) Greene	0	0	0	0	20	4
SALICACEAE						
Populus tremuloides Michx.	8	8	8	0	0	0
FAGACEAE						
Quercus gambelii Nutt.	0	46	24	9	20	11
Quercus grisea Liebm.	0	0	0	9	40	14
POLYGONACEAE						
Eriogonum alatum Torr.	0	8	4	22	40	25
Eriogonum jamesii Benth.	0	8	4	0	20	4
Polygonum douglasii Greene	0	0	0	4	0	4
CHENOPODIACEAE						
Chenopodiumob longifolium (S. Wats.) Rydb.	0	8	4	0	0	0

TABLE 3—Continued

	PER CENT OF QUADRATS ON WHICH SPECIES OCCUR					
	Cañon bottom (12 quadrats)	North slope (13 quadrats)	Total site I (25 quadrats)	South slope (23 quadrats)	Ridge top (5 quadrats)	Total site II (28 quadrats)
NYCTAGINACEAE						
Allionia divaricata Rydb.	0	0	0	4	0	4
PORTULACACEAE						
Portulaca oleracea L.	0	0	0	13	0	11
SILENACEAE.						
Arenaria confusa Rydb.	17	31	24	0	0	0
Cerastium longipedunculatum Muhl.	8	0	4	0	0	0
Silene laciniata Cav.	0	23	12	0	0	0
Silene pringlei S. Wats.	0	8	4	9	20	11
RANUNCULACEAE						
Aquilegia chrysantha A. Gray	8	0	4	0	0	0
Thalictrum wrightii A. Gray	0	31	16	0	0	0
BRASSICACEAE						
Draba helleriana Greene	0	8	4	0	0	0
Erysimum elatum Nutt.	8	0	4	4	0	4
Heterothrix longifolia (Benth.) Rydb.	0	0	0	17	0	14
ROSACEAE						
Cercocarpus breviflorus A. Gray	0	0	0	9	0	7
Fragaria bracteata Heller	8	31	20	4	0	4
Potentilla atrorubens Rydb.	8	0	4	0	0	0
Potentilla crinita A. Gray	8	0	4	0	0	0
Rosa fendleri Crép.	33	38	36	0	0	0
FABACEAE						
Anisolotus wrightii (A. Gray) Rydb.	8	8	8	26	60	32
Aragallus lambertii Greene	8	23	16	0	20	4
Astragalus accumbens Sheld.	8	38	24	30	80	39
Lathyrus graminifolius (S. Wats.) White	17	62	40	35	60	39
Phaseolus angustissimus A. Gray	0	8	4	0	0	0
Vicia americana Muhl.	17	38	28	26	0	21
OXALIDACEAE						
Oxalis stricta L.	0	8	4	0	0	0
GERANIACEAE						
Geranium fremontii Torr.	25	8	16	4	0	4
Geranium richardsonii Fisch. & Trautv.	0	8	4	0	0	0
LINACEAE						
Linum neomexicanum Greene	0	8	4	0	0	0
EUPHORBIACEAE						
Euphorbia fendleri Torr. & Gray	0	8	4	0	0	0

TABLE 3—Continued

	PER CENT OF QUADRATS ON WHICH SPECIES OCCUR					
	Cañon bottom (12 quadrats)	North slope (13 quadrats)	Total site I (25 quadrats)	South slope (23 quadrats)	Ridge top (5 quadrats)	Total site II (28 quadrats)
RHAMNACEAE						
Ceanothus fendleri A. Gray	17	0	8	9	40	14
Viola neomexicana Greene	0	23	16	0	0	0
APIACEAE						
Pseudocymopterus tenuifolius (A. Gray) Rydb.	0	38	20	48	60	50
GENTIANACEAE						
Amarella scopulorum Greene	0	15	8	0	0	0
Gentiana bigelovii A. Gray	8	8	8	0	0	0
POLEMONICACEAE						
Gilia greeneana Woot. & Standl.	0	0	0	22	0	18
BORAGINACEAE						
Lithospermum multiflorum Torr.	8	23	16	4	20	7
MENTHACEAE						
Prunella vulgaris L.	8	0	4	0	0	0
SCROPHULARIACEAE						
Castilleja trinervis Rydb.	16	54	36	0	20	4
Mimulus langsdorfii Don	8	0	4	0	0	0
Pentstemon gracilis Nutt.	0	15	8	26	40	29
Pentstemon virgatus A. Gray	8	8	8	0	0	0
CAMPANULACEAE						
Campanula petiolata A. DC.	8	8	8	0	0	0
ASTERACEAE						
Achillea lanulosa Nutt.	33	69	52	4	0	4
Artemesia forwoodii S. Wats.	8	0	4	30	0	25
Artemesia mexicana Willd.	17	46	32	0	0	0
Artemesia sp.	0	8	4	4	40	11
Chrysopsis villosa (Pursh) Hook.	8	15	12	44	20	43
Coleosanthus petiolaris (A. Gray) Greene	0	0	0	4	0	4
Conyza coulteri A. Gray	0	0	0	4	0	4
Dugaldea hoopesii (A. Gray) Rydb.	25	15	20	56	100	64
Erigeron divergens Torr. & Gray	8	0	4	0	0	0
Gymnolomia multiflora (Nutt.) Benth & Hook.	17	0	8	4	20	7
Hymenopappus mexicanus A. Gray	0	8	4	17	20	18
Hymenopappus radiatus Rose	0	0	0	13	0	11
Machaeranthera aquifolia Greene	42	77	60	35	20	32
Oreochrysum parryi (A. Gray) Rydb?.	0	0	0	17	20	18
Senecio quacrens Greene?	0	0	0	13	20	14
Solidago neomexicana (A. Gray) Woot. & Stand.	0	38	20	0	0	0
Stevia serrata Cav.	17	0	8	0	0	0
Villanova dissecta (A. Gray) Rydb.	25	0	12	9	0	7

Geranium richardsonii, Viola neomexicana, Amarella scopulorum, Gentiana bigelowii, Prunella vulgaris, Mimulus langsdorfii, Penstemon virgatus, Campanula petiolata, and *Solidago neomexicana.* Site II bears such transitory species and xerophytes as *Poa rupicola, Commelina dianthifolia, Yucca* sp., *Quercus grisea, Portulaca oleracea, Heterothrix longifolia, Cercocarpus breviflorus,* and *Hymenopappus radiatus.* The moss (*Mnium* sp.) was only found in cool, moist and shaded situations, thereby indicating unusually favorable site conditions. The monkey flower (*Mimulus langsdorfii*) was the only plant which was confined to the proximity of water, indicating excessive soil moisture conditions.

Practically all of the species listed as occurring entirely on Site II, which do not overlap on other sites, were found in hot, dry and unshaded situations and might be regarded tentatively as indicators of poor western yellow pine sites in the San Mateo Mountains. The mesophytes listed as possible Site I indicators were not found on poorer sites in this locality. However, it may be true that further detailed studies in the San Mateo Mountains might require a different listing of the vegetation than that here given. A number of the species listed as occurring on only one site are, to the writer's personal knowledge, known to occur on different sites in other parts of the Southwest. The vegetation on Site II was comparatively sparse and more open than on Site I where it was also more luxuriant and vigorous. Those species which were found to overlap on both sites normally made their optimum development on Site I. Approximately twice as many species were found on Site I as on Site II. It is therefore with some reluctance that certain opinions are advanced regarding the indicator significance of the natural vegetation. The writer is not attempting, however, to state that certain species are positive site indicators or that others are negative indicators. The rather superficial nature of the field observations will only permit of a few more or less general statements concerning the latent possibilities in the use of the native vegetation in the classification of forest sites and in the determination of their productivity.

In studying the indicator significance of the native vegetation it is necessary to go directly to the individual species instead of attempting to stop at the association, society, or community, since the vegetation as an integral is composed of individual species and in intergrating the vegetation it must be remembered that the behavior of the vegetation is a resultant function of the behavior of the component species. It is impossible in arid and semi-arid regions having many diverse biological growth forms, to select a group of plants which may be regarded as associates without finding that the association may have been disorganized elsewhere and that some of the individuals enter into other associations as component parts.

It is freely admitted that the best ultimate criterion of site quality is the increment of the aborescent species concerned, as judged by the measurement of an approximately fully stocked stand. In cases where the increment data are rather meager or are entirely lacking the native vegetation present should serve as a valuable criterion of site for those species addicted to growing in rather open, park-like stands, such as western yellow pine. In this connection it should be remembered that a plant rarely requires more than a few years at most to reach the adult form, while the forest often requires a century or even two in which to reach maturity. The writer believes that the native vegetation found on deforested areas may be considered as a criterion of the latent potentialities of the site for forest production provided the vegetation has not been too severely and too recently disturbed and that the more important phases of the successional series are properly understood.

Studies are under way at the Utah Forest Experiment Station in central Utah, the object of which is to determine the feasibility of using native plants as indicators of suitable forest planting sites. By making detailed studies of the root systems and subterranean moisture-absorbing surfaces of the typical herbaceous, shrubby and arborescent species of each important association, the value of the native vegetation as indicators of those climatic and edaphic conditions under which the important coniferous species may be planted successfully should be determined. The studies of the depth and character of the root systems will lead to the determination of the different successional stages of the native vegetation on burned-over or cut-over land. It is very probable that the sudden removal of the vegetative cover renders the site less favorable for the successful establishment and optimum development of the climax species and the more favorable for the invasion of species normally occurring on poorer sites at lower elevations.

The fundamental study of forest planting sites logically resolves itself into three categories: (1) the empirical establishment of plantations and the observation and study of their survival and subsequent development, (2) the measurement and study of the most important physical factors of the site, such as the available soil moisture or growth water and evaporation, and (3) the indicator significance of the native vegetation occurring on the sites implying a very careful correlation of all three phases, especially the correlation of the species with the physical conditions which produce them, and a study of the relative transpiration of the natural and planted vegetation.

It is readily conceivable that site studies of this character will be of the utmost value in explaining the presence or absence of tree growth on certain areas, in the judicious selection of the proper species and sites in the reforestation of much of the denuded forest land of the United States, and in establishing a working basis for the classification of the potential productivity of forest lands. Only after considering the relative agricultural and forest productivity of the land on a combined scientific and economic basis, can a positive conclusion be reached that its greatest utility lies in its use for forestry or for agricultural purposes.

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Commission of Conservation
CANADA

COMMITTEE ON FORESTS

Forest Regeneration on Certain Cut-over Pulpwood Lands in Quebec

BY

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Forest Regeneration on Certain Cut-over Pulpwood Lands in Quebec

BY

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Faculty of Forestry, University of Toronto

BEFORE describing certain investigations on cut-over pulpwood lands in Quebec, I desire to make a few remarks upon the general situation. The necessities of war are driving home to us the importance in our national economy of natural resources, among which our timber resources take a leading place. There never was, and, for years, never will be, a time when it is more important for us to know what our timber resources really are, not only in terms of board feet and cords, but also in terms of their application to new uses.

For thirty years, in meetings similar to this, we have been discussing the management of our timber resources, but what have we accomplished? Of many facts, fundamental in the efficient management of the timber resources of the country, we are woefully ignorant. For example, what do we really know about the extent of the timber and pulpwood resources of Ontario and Quebec, though these provinces, combined, contain the largest timber-producing area in Eastern Canada? Where else is there such a large timbered area, containing so many valuable species, with such wonderful transportation facilities, both natural and artificial, and so near, relatively, to the great markets of the world?

This great timber-producing area has been right in our back yard all these years. It now has along its borders a population of 5,000,000, whose consumption of wood products is increasing every day; and just over the fence are the populous Eastern States, with their urgent demands for Canadian wood products. In the face of constantly widening markets and increasing demands, have we really made any methodical, sustained effort to determine the possibilities and the potentialities of the timber resources of Ontario and Quebec? Do we know whether this area can meet the demands now being made upon it, to say nothing of the much greater demands in the future? The United States is thoroughly alarmed over its declining pulpwood supply; we are so ignorant of ours that we do not know whether to be alarmed or not. Is that an enviable situation for an intelligent and progressive people?

THE PROBLEM ANALYZED

Survey of Pulpwood Resources

There are at least three definite lines of enquiry to be pursued in connection with the problem of our pulpwood supply. In the first place, there should be a definite stock-taking of the commercial material now available. We must know what we have before we can make any sensible plans for the future. Not every acre, nor even extensive areas, should be actually cruised, for the results would not justify the expense; but sufficient cruising should be done and enough data gathered to permit of reliable estimates being made. Such work has already been done by the Commission of Conservation in British Columbia, and it is under contemplation for Ontario.

Estimates of the available commercial pulpwood supplies in the province of Quebec have been made, but, as yet, there has been only a partial methodical stock-taking, despite the fact that Quebec is the most important pulpwood area in Canada, supplying over one-half of the pulpwood produced in the Dominion. Nearly half of the pulp mills in Canada are situated in Quebec. With her long southward-flowing rivers, extending into the very heart of the pulpwood regions, with her water and rail connections, Quebec is much nearer the ultimate market for most pulpwood products than any other province with an equal supply of material. Indeed, this very accessibility increases the danger of early exhaustion of her supply. Logically and economically, Quebec should be the first to institute a thorough-going investigation of her present supply of pulpwood.

Rate of Growth

Once we have taken the initial step of ascertaining how much pulpwood we have in Eastern Canada, its distribution and its accessibility, we can, with a known rate of consumption, make a reasonable prediction as to the duration of the supply. Since, however, we are dealing with living wood substance, which has the wonderful power of regenerating itself each year, we must take another factor into consideration, namely, the rate of growth or, in other words, the annual accumulation of new wood fibre in our spruce and balsam forests. This brings us to our second line of enquiry, viz., a detailed study of growth and production, involving the making of stem analyses on carefully selected areas. To be sure, this is little less than drudgery; it is tedious, heart-breaking work, especially if done in 'fly' time; but it is only this kind of investigation that can furnish data by which a ratio between the annual accumulation of wood fibre and the amount annually removed by the pulpwood operations, can be established. This ratio is essential to a reasonably accurate prediction of the duration of the pulpwood supply.

Reproduction of Pulpwood Species

The replacement of the pulpwood removed by any agency is brought about in the first instance by the growth of the small non-commercial trees already on the area. These, in turn, become of commercial size, they are eventually cut, and their place must be supplied by new individuals. New spruce and balsam must establish themselves in the forest if the supply of pulpwood is to be continued beyond one generation of trees. Therefore, the third line of enquiry to follow in order to solve our problem, is the rate of reproduction of the pulpwood species on the cut-over pulpwood lands. If the logging operations, or the fires which often follow them, change conditions to such an extent that spruce and balsam cannot maintain themselves in their former commercial quantities, the supply of pulpwood on those areas cannot be maintained.

Growth and Reproduction in St. Maurice Valley

Investigations to determine the rate of replacement of pulpwood material by growth and by reproduction on cut-over lands, were carried out by the Commission last summer. Through the generous co-operation of the Laurentide Company and its forester, Mr. Ellwood Wilson, the work was carried on in the holdings of this company in the lower portion of the St. Maurice valley in Quebec.

Balsam Predominant

The forest here contains patches of pure hardwoods and patches of pure conifers, but mostly they occur in mixed stands. Numerically, balsam leads in the mixture, with 36 per cent, yellow birch comes next with 26 per cent, and spruce, which, by the way, is practically all red spruce and not the same as the black spruce, as is generally supposed, makes up 20 per cent of the forest. The minor species are cedar, 7.3 per cent; sugar maple, 5 per cent; paper birch, 3 per cent; hemlock, 1.4 per cent; and beech, 1.3 per cent. This type of forest occupies between two-thirds and three-fourths of the region studied. The old burns and the swamps were neglected.

It must be borne in mind that the results and conclusions herein stated refer only to this particular forest type and are in no way to be construed as applying to other portions of the St. Maurice valley, or of Quebec.

Survey by Strip Method

As already stated, the chief object of the investigation was to determine the condition of these cut-over lands with respect to the degree of regeneration and the rate of growth of the present pulpwood-producing species, namely, spruce and balsam. Sample plots were made by the strip method. These strips, run on a compass line, were one-half chain wide and varied in length from 1 to 80 chains. All the trees on the strips above 8 inches in diameter were calipered. Those from 8 to 4 inches in diameter were classed as poles, while those 4 inches in diameter down to trees breast high, were designated as saplings. At the end of every second chain, a square rod plot was marked out and the number of seedlings on it counted, any tree less than breast high being considered a seedling without regard to its actual age. The number of seedlings per acre was calculated on the basis of these square rod plots. The ages of the seedlings in relation to the time of the cuttings were also determined. The stumps on the strips were also calipered and the age of the cutting determined. The total area of the sample strips on which the trees of all sizes were thus measured, counted, and classified, comprises 60 acres.

The growth studies were made for the most part on four sample plots varying from 1/10 to 1 acre in size. Every coniferous tree larger than a seedling on these plots was cut and a complete stem analysis made of it. In this manner, the rate of growth of some 2,000 trees was determined.

The Forest Primeval

The original forest in the southern portion of the St. Maurice valley was undoubtedly dominated by pine, probably, for the most part, white pine. We found, on the average, 6 pine stumps to the acre still standing. This is the average of all the sample plots taken in all the various conditions. Only 8 of the sample plots failed to reveal at least one pine stump, and on some, the pine stumps ran as high as 20 per acre. Considering that the first cutting of pine in this region took place between 60 and 70 years ago, and that there has been practically no cutting of it for 30 years, thus allowing 30 to 70 years for the stumps to decay, it is quite remarkable that the average of all conditions should yield 6 stumps to the acre still recognizable as pine. Undoubtedly, we are safe in assuming that the original number of pine trees was considerably more than 5 per acre.

Formerly a Black Forest

However, I do not think of the original forest as having been a pure stand of pine. Although pine was biologically dominant, it was outnumbered by other species. I picture the original forest as having a distinctly two-storeyed crown cover. The lower storey was a mixed forest of yellow birch, maple, spruce, and balsam, in abundance in the order named. Towering 50 or 75 feet above this were scattered giant pine trees from 3 to 6 feet in diameter, from 100 to 150 feet high, and probably 200 to 300 years old. Had there been only six such trees to the acre, they would have dominated it, but there were probably more, but not sufficient, however, to form a complete crown cover in this upper storey, except on rocky ridges. In the latter situations we often found from 20 to 30 big pine stumps to the acre, evidently indicating a pure stand. To one flying over the region at that time in an airplane, it would have appeared as a 'black' forest, that is, one in which the pines predominated over the hardwoods.

Passing of the White Pine

To-day the conditions are reversed; it is a 'green' forest, that is, one in which the hardwoods predominate. This change of conditions in the past 50 to 70 years is very interesting biologically, but it also has an important commercial significance. Those areas which have yielded enormous quantities of white pine are, commercially speaking, denuded of that species to-day; only scattered groves on rocky, inaccessible ridges and elsewhere an occasional tree towering above the hardwood forest, remain. Not only this, but of still greater significance to the future, white pine is not reproducing itself; there are practically no young trees in the forest. Except on the borders of lakes, the margins of swamps, and around old camp clearings, we did not see, under the normal forest cover in our investigations last summer, two dozen young pine trees. Yet we found old pine stumps everywhere. I can show you areas which once had 20 pine trees to the acre, but are without even a young pine tree to-day. Moreover, there are no coniferous trees in the crown cover—only a solid mass of yellow birch and hard maple.

Why a Green Forest Now ?

There are, however, abundant balsam and spruce beneath this crown cover ready to push through whenever opportunity offers. Note especially that the areas of which I am speaking have never been seriously devastated by fire, the chief cause of the failure of white pine reproduction in Canada. Why, then, have these areas changed within the life time of some of my audience, from a dominant pine to a dominant hardwood forest? Why did the pine not reproduce itself after logging and so maintain itself in the forest? The hardwoods were probably originally more or less suppressed by the pines, both by shading and root competition. The removal of the pine stimulated the development of the hardwoods so that they soon filled up the gaps. The crown cover below the pine was probably continuous and cast a deep shade. The luxuriant underbrush formed another shade-producing layer. These two layers excluded so much light that the young pine trees could not develop. The seeds doubtless germinated and the seedlings may have persisted for some years, but not receiving sufficient overhead light, they were eventually crowded out by the shade-enduring hardwoods.

Over 100 Years for Spruce to Grow

These some-time white pine areas were subsequently cut over for spruce saw logs or pulpwood at least twice and some of them three times. Our growth studies show that all the spruce trees since removed by lumbering operations were present in the original forest beneath the pine trees. They were at least 6 inches in diameter and about 100 years old when the pine was cut. Many lumbermen think that the second cutting on an area is from young trees which have grown since the last cutting. The area which we are describing has been cut two or three times in the last 30 years and the youngest spruce cut was over 100 years old, most of the trees being more than 150 years old. This is the length of time that it takes to make a spruce forest from seed to pulpwood size, when the spruce grows up in company with hardwoods.

Seventy Years for Balsam

The situation is somewhat different, however, in the case of balsam. Some of these trees now being cut for pulpwood were seedlings scattered on the floor of the original forest at the time the pine was first cut, that is, 70 years ago.

We counted and measured the stumps on all our sample plots. The spruce stumps averaged 22 per acre. At the present time, there are 6 spruce trees per acre entering the crown cover and over 70 years old. Therefore, at the time of the first cutting 70 years ago, there were 28 spruce trees 8 inches or more in diameter on the average acre. It is interesting to note in this connection, that according to Mr. Ellwood Wilson, forester to the Laurentide Company, there are 26 spruce trees 8 inches and upward in diameter in the virgin forests farther northward in the St. Maurice valley. This result is derived from cruising surveys, totalling over 1,000 acres and representing about 3 per cent of the area through which the strips were run.

Thus, you see that the number of spruce trees has been reduced from 28 per acre to 6, a reduction of nearly 80 per cent, by the lumbering operations of the past 30 years, the period during which spruce has been cut for saw logs. Our results show practically the same number of balsam as spruce trees taken from the average acre, namely 22, and the number of balsam larger than 8 inches in the present forest is also practically the same—6 per acre.

Black to Green in 30 Years

Let us go back and look a minute at the original forest, a pine forest with a mixed spruce-balsam-hardwood under-storey, giving the general impression of a 'black' forest. The pine was cut and did not re-establish itself; 80 per cent of the spruce and perhaps the same amount of balsam was cut. The result: within 30 years a 'black' forest was changed to a 'green' forest; it was changed from a softwood forest, to a hardwood forest.

Its Economic Significance

Very interesting, you say, but what of its economic importance? It is this: the pine and spruce and balsam are valuable, but the hardwoods, the beech, birch, and maple are, so far as we know, valueless, being too far from markets to be utilized at the present prices. Let me state the case from another standpoint. The sum of the basal areas of the spruce *stumps* of the various diameters on the average acre is 25 square feet. The basal area of the spruce remaining on the average acre is only 5 square feet. The volumes of trees are proportional to their basal areas. This means that the capital stock and, therefore, the earning capacity of those areas are only one-fifth of what they were originally.

Young Growth

There is, however, at least one other point which we should investigate carefully before we become too pessimistic in regard to the future of these cut-over lands. I refer to the young growth, the spruce and balsam trees not yet of commercial size. Are they in sufficient abundance to insure another crop? If so, when can we expect that crop? As already stated, these are the two principal questions we had constantly before us in our work last summer.

Here is the answer to the first question:

Species	Seedlings (trees up to 1-in. diameter)	Saplings (1-in. to 4-in. diameter)	Poles (4-in. to 8-in. diameter)	8-in. to 12-in. diameter	Total	Per cent
Spruce............	635	99	30	6	770	14.8
Balsam...........	3972	161	59	6	4198	80.8
Cedar.............	180	32	8	..	..	4.2
Hemlock..........	8	2	1	..	11	0.2

Mortality Rate

At first glance, this looks very bright for the future, but let me refer once more to the mortality rate. There are 635 spruce seedlings per acre, but when they get up near commercial size, they are all dead but 6. The percentage of loss is still greater in the case of the balsam. In the beginning, there are 6 times as many balsam as spruce, but when the balsam gets into its commercial class of 7 inches diameter, there are only about twice as many.

You may say that the conditions have changed since the '8-in. to 12-in.' trees came through the forest cover and a larger percentage of the smaller-diameter classes will survive. You may be right. Conditions certainly have changed, but my impression is that, from the standpoint of the spruce at least, and perhaps also for the balsam, they have changed for the worse. Each logging operation has stimulated the growth of the hardwoods more than that of the softwoods. The crowns of the large trees soon fill in the gaps and a dense thicket of hardwood shrubbery is developed on the forest floor, thus producing more shade and suppressing the spruce and balsam still more.

Outlook for Spruce

Turning now to the '4-in. to 8-in. diameter' class, we find 30 spruce and 59 balsam on the average acre. Twenty of the spruce and 40 of the balsam are dominant and they stand a good chance of persisting. If they should all enter the commercial class, they would furnish a sufficient future supply *in time*. 'In time'—that is the second phase of our investigation. When can we expect another crop? Our growth studies showed that the spruce trees in the '4-in. to 8-in. diameter' class were from 80 to 100 years old, and those of the '8-in. to 12-in.' class were from 100 to 150 years old. Therefore, it would take at least 50 years for the upper range (8 inches) and 70 years for the lower range of the class (4 inches) to reach the 12-in. minimum diameter limit for spruce in Quebec. I think you will agree with me that 50 years is too long for any private concern to wait for another crop of spruce on these cut-over pulpwood areas.

Outlook for Balsam

The present increased demand for woodpulp has led to a rapid increase in the proportion of balsam used. So, if our 40 dominant balsam between 4-in. and 8-in. on the average acre reach commercial size, they would represent a valuable asset. In fact, some in this class are already commercial, for the minimum diameter limit for balsam in Quebec is 7 inches, but, unfortunately, the number of this diameter cannot be segregated from the '4-in. to 8-in.' class. However, according to our growth tables, it takes only about 10 years on the average for a balsam to pass from a 4-in. tree to a 7-in. tree; so, within that time there will be another crop of balsam on these areas.

Several factors, however, greatly reduce the value of balsam. As is well known, it is much subject to disease and windfall. Mr.

Wilson finds that, on the average, 44 per cent has butt rot. In certain conditions, we found as many dead trees as living. One rarely sees a balsam tree 14-in. in diameter and the great majority never get beyond 9-in. before death overtakes them. Such small trees scattered through a mixed stand may raise the logging cost to a prohibitive point.

MEASURES FOR REFORESTATION—HARDWOODS *vs.* SOFTWOODS

We come now to a consideration of what is to be done with these cut-over pulpwood lands. They belong to a provincial government and are leased by private corporations, chiefly by companies manufacturing paper pulp. They should, therefore, be considered from the standpoint of both these interests.

The Individual's Viewpoint

First, let us look at the matter from the standpoint of the private company. So far as another crop of spruce on these lands is concerned, the case is hopeless. No private concern could afford to wait 50 years, paying annual rental for that length of time for the sake of a few cords of pulpwood, probably less than three, per acre. The amount of balsam obtainable in the near future is problematical until we have had an investigation of the rate at which the everywhere prevalent heart rot is progressing.

Utilizing the Hardwoods

If the hardwoods could be utilized without too much destruction of the young spruce, the problem might solve itself. At present, the market for them is so far distant and the difficulty of transportation is so great that they are apparently valueless. However, some investigations of possibly great significance are about to be instituted by the forester to the Laurentide Company. Trials are to be made of the applicability of paper birch for pulpwood. There are enormous quantities of this in Quebec, impeding the growth of the spruce and balsam by its shade. It may be possible to establish a rotation between the softwoods and hardwoods and so keep the land continuously productive.

Birch for Railway Ties

The possibility of the use of yellow birch for railway ties is to be investigated. There is no doubt of the market for this purpose. The question is whether they can be profitably handled at present prices. If it proves profitable, the over-topping birch would be removed and a much larger portion of the 700 young spruce trees to the acre might develop into pulpwood.

If these possibilities become actualities, then the private concerns will not be compelled to surrender their leases.

The Government Viewpoint

Since these lands are to be held in perpetuity, it may be that their productive capacity in terms of spruce could be increased by raising the diameter limit, say to 14 inches. A conclusive determination of this point would involve a careful study of the comparative rate of growth of the trees 12 and 13 inches in diameter, and whether the increased growth, if present, or the increased stumpage value, would outrun the compound interest charges on the extra capital invested in the 12-inch and 13-inch tree. Since, however, at the present time, one finds only one 12-inch spruce tree on 5 acres and one 13-inch tree on 10 acres, and since, according to our growth studies, it will be 100 years before the 30 trees per acre in the 4-inch to 8-inch class will get into the 14-inch class, I have not made the computations necessary for the discussion of the benefit of raising the diameter limit.

There is, however, another consideration that seems to me important in determining the future of the lands from the government's standpoint. The hardwoods are at present biologically dominant on these areas. It may be that this is what nature intends, and that we have too great a handicap to overcome in trying to put the spruce back by natural means. Certain investigations to which I will refer later, may throw light on this point. If nature is really against us, it might be the best thing to cut every acre off clean, if a market could be found for the hardwoods, and start the spruce anew by planting. An experimental plot of this kind, of 60 acres, has already been inaugurated by the forester to the Laurentide Company, and its development should be watched with much interest. It may be that, even here, the biological conditions will prove the more favourable to the hardwoods and keep the spruce always in a subordinate position.

Lack of Accurate Knowledge

We talk easily of what we should do with a forest. In this particular case we want to increase the production of spruce, the most valuable species at present on this cut-over land, or at least, we would like to restore it to its former position in the forest. How can this be done? One man says: "Cut heavier, open up the crown cover, let in the light." Another man says: "Make a lighter cut, disturb natural conditions as little as possible." The result cannot be obtained by methods so directly opposed. What is the answer? The answer is that neither man really knows what he is talking about. Your opinion may be just as good as mine, because both have been spun out beneath our hats, or evolved from smoke rings, as we sat in our office chairs. We have no accurate knowledge, no definite records, no actual measurements by instruments of precision, of the conditions as they really exist in Canadian forests. I repeat what I said in the beginning. We have been discussing the management of our timber resources for 30 years, but, as yet, we have not the fundamental knowledge of conditions on which it is necessary to base our plans, if we were asked to-day to put them into operation. What definite knowledge we do have as to conditions in which trees grow is borrowed from other countries, even European countries, whose conditions are not our conditions. Is it any wonder that we are groping in the dark? And we will continue to grope in the dark with this matter until we obtain actual experimental records of those environmental conditions that fashion a forest.

Experimental Procedure

Let me illustrate what I mean by using the Quebec cut-over pulpwood lands as an example. Here we have over 700 young spruce trees to the acre growing beneath a birch-maple forest. Normally, only one per cent of them lives long enough to make a commercial tree. The problem is to determine whether opening up the overshading crown cover to various degrees would bring a larger number of these suppressed spruces to maturity and thus increase the value of the land to the owner. To solve the problem, in certain plots, a light cull, a medium cull, a heavy cull, and a clear cut of the over-topping hardwoods should be made; and then, a definite record of results kept during a series of years. The intensity of the light exposure on each plot should be measured periodically; the rate of the filling up of gaps by the side growth of the tree crowns should be measured; the behaviour of the shrubby layer should be noted; any changes in the humus content or in other soil conditions should be studied; the height growth and the diameter growth of the little spruces should be measured periodically, at least every fifth year. The trees that show stimulated growth should be studied very carefully in respect to their root development, the moisture condition of the soil in which they are growing, the relative number and the size and vigour of their leaves.

Inherent Dominants

The necessity of studying the *successful* trees is emphasized because they may be the key to the whole situation. In a nursery bed, certain seedlings are more vigorous than the majority, making three or four times as much growth in a season as their companions. Now, it may be that they are inherent dominants, and once dominant, always dominant. We know there are inherent dominants among animals, including man. Why not among trees? If this be the case, why waste time and money planting any trees but dominants. It may be that those which survive in the struggle for existence in the forest are those which are predestined to survive from the beginning. The truth or falsity of this suggestion is capable of being demonstrated by field experimentation and, logically, is the first problem to be solved, for, if true, it would automatically solve many other problems as well and render further experimentation along certain lines unnecessary.

To Determine Effect of Light

One more illustration of the necessity of field experimentation. Why is the young balsam so abundant and so aggressive in the logged-over forests; why is it more successful than the spruce, its principal competitor? Unless checked by its greater susceptibility to disease, balsam may, in time, dominate all our northern forests—no longer pine forests, no longer spruce forests, but balsam forests. Why the dominance of balsam reproduction? One man says it is because the balsam can endure more shade than the spruce, and another says the spruce can endure shading better than the balsam. One man makes the first statement in one of his papers, and the last one in another; and one of our best authorities makes the two contradictory statements between the covers of one book. Personally, I think the importance of light as a determining factor in the forest has been very much over-estimated by foresters. We have accepted it as a kind of tradition from our fathers, as we accept other traditions, without thinking very much about it and, still less, subjecting it to experimental proof.

Experimental plots should be established in the forest where the balsam and spruce seedlings are growing naturally and the light intensities should be measured in the two cases. Not only this, but other points need investigation, such as the comparative vigour of the roots of the two seedlings, their ability to penetrate the leaf litter in order to reach the mineral soil; their relative ability to endure drought; the rate and abundance of root growth in the two cases. With data of this kind, the result of measured records of environmental conditions, we could determine the reasons why certain methods of lumbering encourage the growth of balsam and discourage the growth of spruce. With such data, we could discuss with intelligence the means by which to increase the production of spruce pulpwood in Quebec.

To improve upon nature, we must first know how nature acts and reacts upon the thing we wish to improve. This is so self-evident as to be axiomatic, but, thus far, we have made no determined and sustained effort to get such data in regard to the forest. This has been the basis of plant and animal breeding and it must be made the basis of forest breeding. We must not be deterred because trees grow more slowly than other plants and, definite results are, therefore, slower of attainment. It will require patience, perseverance, and time, but when it is done, we will have reliable data on which to base our plans and will be in a position to manage out timber lands intelligently. We could substitute a *real* policy for the trust-to-luck-and-nature policy of the past, in which both luck and nature have been against us, and which has already reduced a large portion of our incomparable forest heritage to the condition of waste lands.

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STUDIES IN JUGLANS, III

(1) FURTHER EVIDENCE THAT THE OAK-LIKE WALNUT ORIGINATES BY MUTATION

BY

ERNEST B. BABCOCK

In previous studies[1] the conclusion was reached that the oak-like walnut, *Juglans californica* var. *quercina* Babcock, was first produced as a result of germinal variation in a tree of the southern California black walnut, *J. californica* Wats., and that the several recurrences of this peculiar walnut resulted from repetitions of the same mutation. It is the purpose of this paper to report further evidence showing that this conclusion was correct at least as regards the origin of the first *quercina* individual, although this same evidence may lead to a different explanation of some of the recurrences of this form.

This evidence consists of the results from hybridizing *quercina* and *californica*. In 1908 pollen from the original, fertile, type individual of *quercina* was applied to several guarded pistillate flowers on a typical *californica* tree. The eleven F_1 seedlings secured are growing on the campus of the University of California. They are all normal *californica* trees. The only evidence of heterosis thus far observed is length of staminate catkins, which is intermediate between the two parents. In 1915 several of these F_1 trees were self-pollinated, or interpollinated, and thirty-six seeds were secured. Up to the present eighteen of these have germinated, producing twelve *californica* and six *quercina* seedlings, which is a ratio of 2.67 to 1.33, a deviation from the theoretical monohybrid ratio which might be expected to occur under the laws of chance in 42 per cent of monohybrid populations. While positive statements will not be made until the F_1 trees have been tested on a more extensive scale, yet a valid 3 to 1 ratio even with so few F_2 individuals is certainly an indication that the genetic relationship between *californica* and *quercina* is a difference in a single factor of the same Mendelian reaction system.

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[1] Babcock, E. B., Studies in Juglans I and II, Univ. Calif. Publ. Agric. Sciences, vol. 2, no. 1, 1913; no. 2, 1914.

The idea that a single factor-difference may so affect the entire chromosome system that the individual is altered more or less in each somatic detail is now generally recognized, yet the direct evidence on which this conception is based is found in a limited number of cases. Morgan[2] refers to the mutant strains of *Drosophila ampelophila* called ''club'' and ''rudimentary'', in which the factor for a certain wing character also conditions the development of certain other morphological and physiological characters. But, thus far in *Drosophila,* no single factor has been found that visibly affects every external feature of the organism. The well-known dwarf or cupid sweet pea is a striking example of the manifold effects of a single factor. This variety differs from the ordinary climbing form of *Lathyrus odoratus* not only in its extremely dwarf stature but also in color of foliage, length of internodes, size and arrangement of flowers, time of anthesis, fertility and viability. Yet it is certain that the variety differs from the species in a single genetic factor. Probably this is as striking a case as has been reported previously, yet in such a conspicuous character as leaf-shape the dwarf variety very closely resembles the species type. Now the oak-like walnut differs from the species type in every gross external feature—shape of leaves, color of foliage, color of bark, habit of growth, structure of inflorescence, structure of flowers, size and structure of fruits, as well as in fertility and viability. Therefore, if tests that are now being made confirm our inference that *quercina* differs from the species in a single genetic factor, it will be a most striking example of the manifold effects of a single genetic factor. Furthermore, the demonstration of such a genetic relation between *quercina* and *californica* must be accepted as ample proof that the first *quercina* individual, at least, originated by mutation.

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[2] Morgan, T. H., Mechanism of Mendelian Heredity, p. 209ff., 1915.

Since the mutant factor is recessive to its normal allelomorph, it is highly probable that *californica* trees which are known to produce *quercina* seedlings are not to be considered as mutating individuals. Such a tree is *J. californica*, "Garden Grove No. 16", which was referred to in the preceding number of this series. This tree may be either the result of a mutation in one of the gametes that produced it, in which case it would, of course, be heterozygous, or it may be a heterozygote produced by hybridization between *quercina* and *californica.* The same is true of the other two *californica* trees known to have produced *quercina.* But the genetic relation between the variety and the species shows that the first production of *quercina* at least must have been caused by a mutation in one genetic factor and that this change occurred in all probability in a germ cell of the grandparent of the first *quercina* tree.

A question arises as to the interpretation of the test of the particular *californica* tree, Garden Grove, No. 16, reported in the preceding paper. In 1913 the unguarded seed from this tree produced about 5 per cent of *quercina* seedlings. The fact that the seed was not self-pollinated under control and so may have been crossed with nearby trees may serve as an explanation of this result. However, another explanation is indicated. This tree is very late in developing its pistillate flowers, the stigmas becoming conspicuous after most other trees have shed their pollen and after this tree has shed much of its own pollen. Now if only a portion of its pistillate flowers are self-pollinated the remainder probably develop apogamously. That would account for fewer *quercina* seedlings than would be expected from self-pollinated seeds in case this tree is heterozygous for the *quercina* factor. For only one-fourth of the self-pollinated nuts would produce *quercina* seedlings, whereas all apogamous seeds would produce *californica* individuals. Presumably all such apogamic plants would contain the diploid number of chromosomes. Hence they would be heterozygous like their parent and for this reason they would be *californica* in type.

There is also the remote possibility that unfertilized pistillate flowers might develop parthenogenetically, the egg-nucleus, containing the haploid number of chromosomes, developing spontaneously into an embryo. In order that such seeds should produce only *californica* individuals it would be necessary that a single dose of the *quercina* factor could not condition *quercina* development even in plants having the reduced number of chromosomes. This is at variance with the concept that Mendelian reaction systems depend upon proportional chemical relations such that one dose of a recessive factor would play the same rôle in an individual having a haploid system as two doses of the same factor play in an individual having a diploid system. Therefore, the former is the more reasonable interpretation.

(2) A PARALLEL MUTATION IN *JUGLANS HINDSII* (JEPSON) SARGENT

In November, 1914, through the courtesy of Farm Adviser F. F. Lyons, my attention was called to a nursery at Modesto, California, where there were several thousand one-year-old seedling walnuts. Here and there among the typical black walnuts I found a number of plants (fifty or more) that closely resembled *J. californica* var. *quercina* except that they were taller than *quercina* seedlings of the same age and the leaves appeared somewhat larger. Through the kindness of the owner, George F. Covell, seven of these seedlings are now growing on the campus of the University of California. These seven and several that were examined at the nursery were found to have come from typical nuts of *J. hindsii*, the northern California black walnut. The trees that produced the nuts which Covell planted in his nursery are also typical of *J. hindsii,* but as they had been grafted to commercial varieties I was unable to secure seeds from them. However these grafted trees are seedlings from four large northern black trees growing near Lodi, California. Several hundred nuts from each of these trees have been germinated and only seedlings typical of *J. hindsii* have been secured. If any one of these trees is repeating the mutation there is no evidence of it in the immediate progeny. This is what would be expected if the new variety has the same genetic relation to *J. hindsii* as *quercina* has to *J. californica*.

In an earlier paper[3] I proposed to designate *quercina* as *J. californica* mut. *quercina* and the *quercina*-like form of *hindsii* as *J. californica* var. *hindsii* mut. *quercina*. However, the recognition of *hindsii* as a species[4] simplifies the problem and makes it desirable to describe the new mutant from *hindsii* as a variety of that species and to retain *quercina* as a variety of *californica*. The following description is based upon material gathered from several of the seedlings in Covell's nursery in 1914. The seven seedlings growing on the campus of the University of California are cited as cotypes. It should be noted that the variety name has been chosen for the express purpose of emphasizing the fact that the new variety resembles *quercina* in leaf characters.

NEW VARIETY

Juglans hindsii var. **quercinifolia** Babcock

Tree. Bark and leaves strongly walnut-scented. Pits in plates. Twigs, bud scales, and young leaves granular pubescent. Buds few-scaled axillary or superposed. Leaves 1 to 3½ inches long, alternate, exstipulate, mostly compound with three leaflets; terminal leaflet 1½ to 2 times as long as lateral leaflets and ranging from ¾ to 2¼ inches in length, in form ovate or elliptical, obtuse or truncate at the apex, margin irregularly crenate or serrate; lateral leaflets mostly opposite and sessile, sometimes one or both lacking, occasionally one or two extra ones present; petiole equal to or shorter than lateral leaflets; very rarely with unifoliolate leaves. (Cf. plate 20, fig. 1.)

Nursery of George F. Covell, Modesto, Cal., Nov., 1914, Univ. of Calif. Herb. no. 189541. Cotypes on campus of the Univ. of Calif. (Cf. Div. of Genetics nos. 755*a* to 755*g*.)

Plate 20, fig. 1 shows a specimen of *quercinifolia* which was supplied by Covell in 1915. A typical *quercina* seedling is shown in plate 20, fig. 3. The relative size of these two seedlings is of no significance as they were not of the same age. In order to emphasize the fact that *hindsii* is distinct from *californica* even in the young seedling stage, a typical seedling of *californica* and one of *hindsii* are shown in plate 21, figures 5 and 6. The differences between the nuts of the two species are clearly shown. The mature trees of the two species are also strikingly distinct, *californica* being always low and shrub-like in habit while *hindsii* is tall and arboreous in form.

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[3] Babcock, E. B., Walnut Mutant Investigations, Proc. Nat. Acad., vol. 1, p. 535, Oct., 1915.

[4] Jepson, W. L., in Smith, R. E., Univ. Calif. Agr. Exp. Sta. Bull. 203, p. 27 (1909). *Juglans californica* Wats. var. *hindsii* Jepson in Bull. So. Cal. Acad. Sci., vol. 7, p. 23 (1908).

These parallel mutations in two distinct species may appear as degressive rather than regressive variations or, in other words, as cases of reversion to a common ancestral form. If both *quercina* and *quercinifolia* resulted from a change in one genetic factor, as seems likely, and both represent a common ancestral form, then it would follow that both *californica* and *hindsii* sprang fully formed from their common ancestor by mutation. Yet both *quercina* and *quercinifolia* show reduction in morphological characters and *quercina* individuals exhibit low fertility. These symptoms would indicate that the mutation is regressive rather than degressive. However, the fact that any walnut varieties originate by mutation is of significance for the student of evolution, because the Juglandacae are generally considered as one of the older and more stable groups of angiosperms. They are not supposed to be undergoing changes similar to changes that give rise to new types in the younger, less stable groups. That the origin of these two unique walnuts, or of *quercina* at least, cannot be explained on the basis of hybridization is now fully proved. Evidently *quercina* sprang from *californica* rather than *californica* from *quercina,* and it arose as a result of a change in a single genetic factor, i.e., of mutation in the strict sense.

Transmitted May 31, 1916.

PLATE 20

Juglans hindsii var. *quercinifolia* Babcock

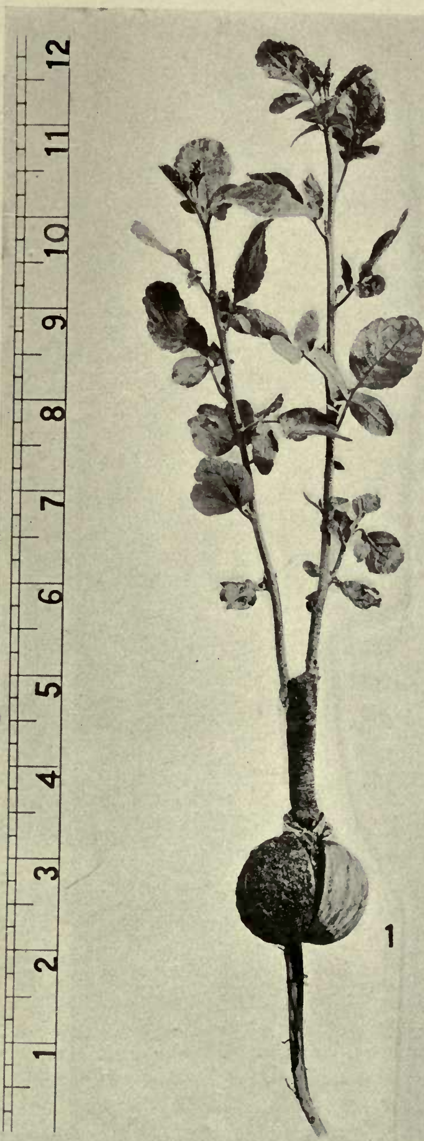
Fig. 1. Specimen from Covell's nursery, 1915. Note typical *hindsii* nut, the husk removed to show the smooth surface. × ½.

Fig. 2. Halves of typical *hindsii* nut. × ½.

J. californica var. *quercina* Babcock

Fig. 3. Seedling of *J. californica,* ''Garden Grove No. 16.'' Note typical *californica* nut. × ½.

Fig. 4. Halves of typical *californica* nut. × ½.



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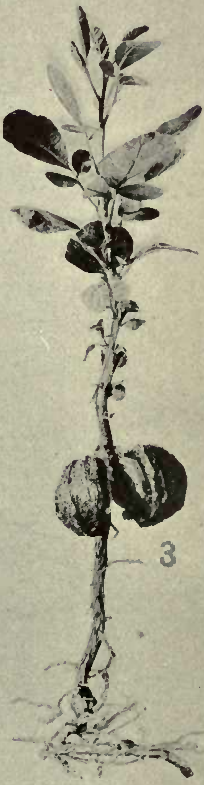

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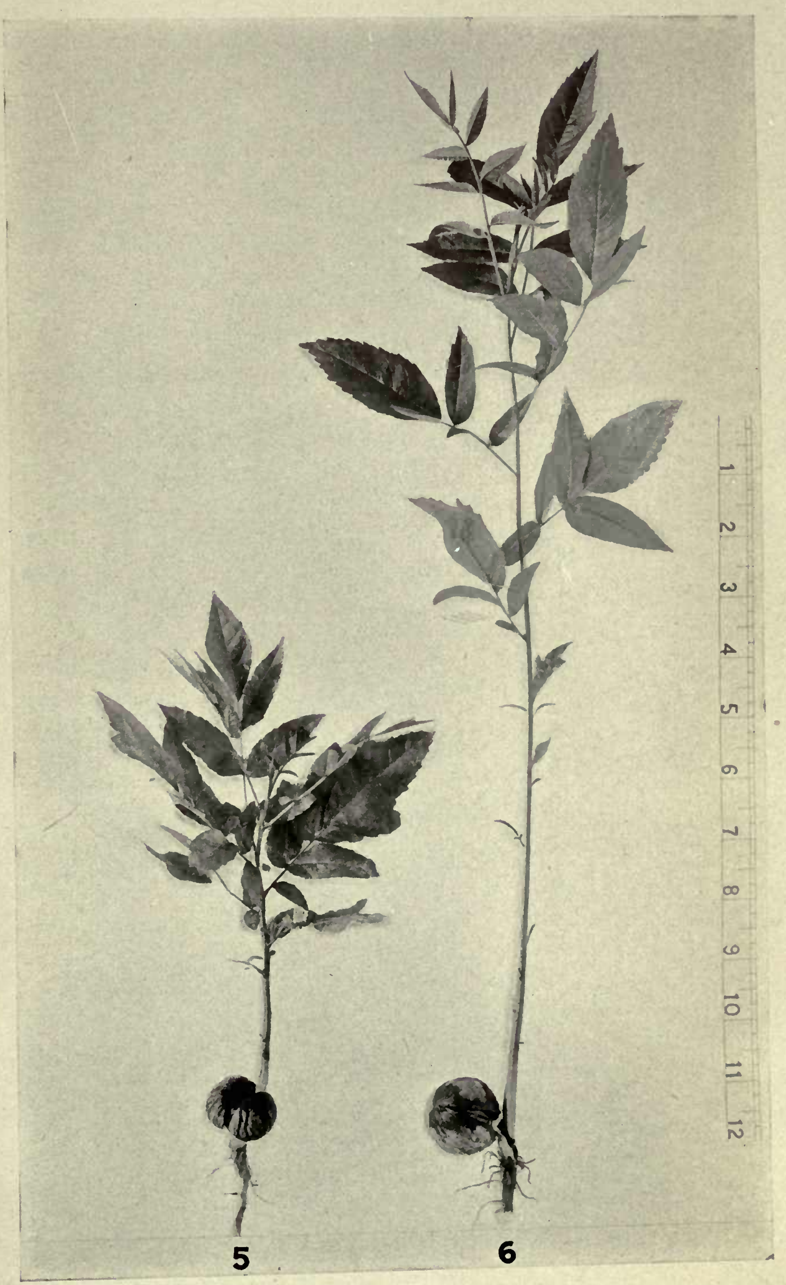
PLATE 21

Juglans californica Watson

Fig. 5. Typical seedling. × ⅓.

J. hindsii (Jepson) Sargent

Fig. 6. Typical seedling. × ⅓.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ACCELERATED GROWTH OF BALSAM FIR IN THE ADIRONDACKS

By E. F. McCarthy

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This study of growth was made following a pulp logging operation in northwestern Hamilton County, near Brandreth Lake, N. Y. The unusual growth of the stand was not discovered until the age classes were computed separately. Diameter growth curves show that each of the age classes was released from suppression about 50 years ago, or possibly half a decade sooner than that.

While the cause and knowledge of the exact time of the release would open the way to new determinations, facts are evident which show new possibilities of balsam pulp-wood production. The suggestion is made that the cause of release was the cutting of a stand of pine which had been sufficiently dense to hold the balsam in suppression.

Measurements were taken on trees cut along the west side of the inlet to Rose pond. The type was characteristically swamp, located on flat bench-lands back from the small stream that drains the valley. The valley itself has a slight slope, but the forest floor is of the spongy, sphagnum type characteristic of true swamps, and the stand of timber of pure balsam-spruce. While there is a distinct drainage to the small valley, the areas from which measurements were taken were swampy, flat benches. The site might have supported a stand of white pine at some time past. The valley opens to the southwest and is flanked on both sides by ridges with a mixed spruce-hardwood cover. The upland was cut for spruce to a diameter limit 20 years ago, but the lowland was not logged, nor was the hemlock on the upland cut.

Field work was carried on in September, following the cutting and peeling of the balsam, but before the trees had been cut up into log lengths. The trees lay where they had fallen, with the tops lopped and cut off at the 4-inch diameter. Decade measurements were made on the stump, counted in and measured out from the center. Record was also made of the total height, merchantable height, crown length, stump height, diameter at breast height inside bark, and a ring count and measurement at the point of cutting in the top. All trees that were cut were taken, except those that were cut with an ax, which were few and small, and those that were decayed at the center on the stump, which were usually large, but amounted to less than 5 per cent of the total. Average measurements were made on all diameters.

The trees were for computation separated into age classes and decade measurements were mathematically averaged. (The fallacy of this method is more than counterbalanced by the advantages in this case.) Results were plotted for comparison only, and the curves have not been varied from the points mathematically determined.

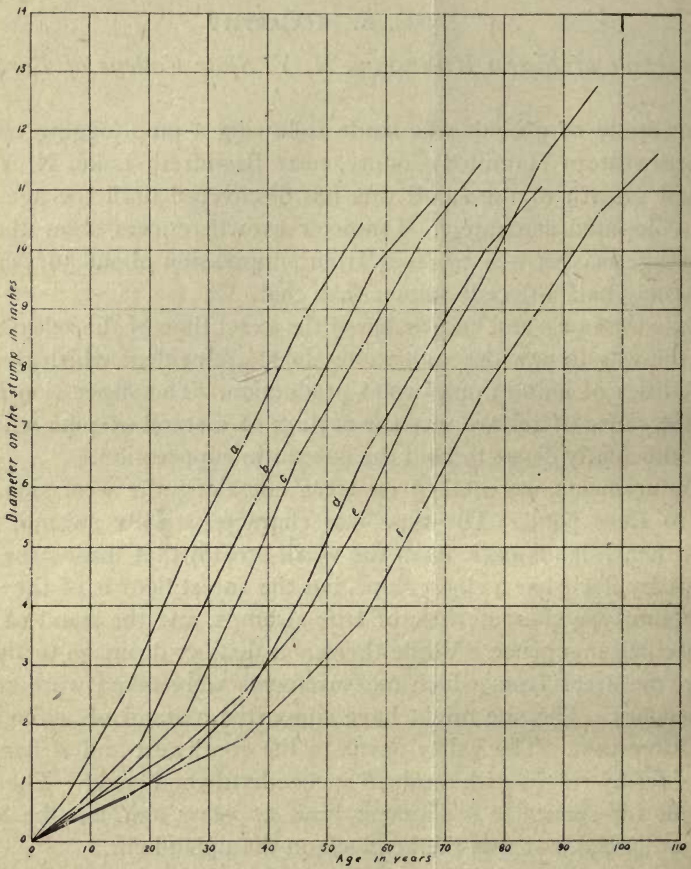

FIG. 1.—Diameter growth on the stump for balsam fir, by age classes, from 208 trees taken on swampy-bench land, Brandreth Lake, N. Y.:

(*a*) 50– 60 year age class.
(*b*) 60– 70 year age class.
(*c*) 70– 80 year age class.
(*d*) 80– 90 year age class.
(*e*) 90–100 year age class.
(*f*) 100–110 year age class.

The following facts may be noted from the diameter growth curves:

1. At a period five decades back from the time of cutting all age classes began an accelerated growth.
2. The largest—that is, the oldest—age class at that time was 3.8 inches on the stump.
3. The younger trees responded more quickly and grew more rapidly than the older.
4. The youngest age class passed through no period of suppression, and was cut for pulp 56 years after it passed the stump height.
5. All age classes show a crowding in the last decade.

Comparisons of the results shown in Table 2 serve to emphasize the comparatively equal development of stem in all age classes and show a larger number of trees in the 60–70 year class than in any other.

The average age of all the trees 50 years ago was 27 years, and the average diameter on the stump for that age 2.16 inches. The average diameter of all trees at the time of cutting was 11.16 inches on the stump, and the average age at that time 77 years.

No complete caliper record was obtained, since the true significance of the stand was not known at the time the measurements were made. It is still possible to obtain such a record from the stumps, and so obtain yield and an idea of the condition of the cut-over area.

This study is sufficient basis for the assertion that a crop of balsam fir, merchantable in the present interpretation of the word, can be produced in 60 years from seedlings. It must be pointed out also that the stand does not show crowding until the last decade, and for this reason would not need thinning during this period of production. No statement can now be made as to the probable loss of trees from the stand during the last 50 years' growth.

TABLE I.—*Dimensions of 208 Trees (Balsam Fir) not Averaged by a Curve*

Diameter breast height outside bark, inches.[1]	Total height, feet.	Average age, years, above the stump.	Volume in cubic feet, total.
9.63	62.7	56	15.84
9.75	63	68	16.30
10.2	64	76	17.96
9.85	64	87	16.90
10.4	64	96	18.60
9.8	64	106	16.70

[1] Bark thickness was taken as .6 inch from U. S. Dept. Agr. Bul. 55. Volume was interpolated from volume table 19, in same bulletin.

TABLE 2

Age class and average age.	Merch. height, feet.	Total height, feet.	Crown length, feet.	D. b. h. ib., inches.	Stump height, inches.	Number of trees in class.
50–60 56	46.7	62.7	31	9.03	11.7	22
60–70 68	47.7	63	31.6	9.15	11	70
70–80 76	48	64	33.4	9.6	12.2	38
80–90 87	47	64	31.3	9.25	11.4	40
90–100 96	50	64	34.4	9.8	12.4	30
100–110 106	47.7	64	32.4	9.2	13.6	8
Total..........	....	....	....	....	....	208

TABLE 3.—*Stump Diameter Growth Table for Balsam*

208 trees. Mathematical averages—not curved

Age class	Diameter in inches by decades										
	1	2	3	4	5	6	7	8	9	10	11
50–60..	.78	2.56	4.64	6.76	8.88	10.48	.....	.....	.....	.....	.....
60–70..	.64	1.64	3.76	5.8	7.68	9.74	10.88	.....	.....	.....	.....
70–80..	.36	1.18	2.16	4.32	6.50	8.40	10.20	11.48	.....	.....	.....
80–90..	.35	.81	1.40	2.42	4.30	6.60	8.28	10.00	11.10	.....	.....
90–100..	.40	1.00	1.52	2.52	3.70	5.46	7.62	9.36	11.40	12.8	.....
100–110..	.32	.78	1.30	1.75	2.72	3.80	5.60	7.56	9.06	10.64	11.64

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THE INDICATOR SIGNIFICANCE OF NATIVE VEGETATION IN THE DETERMINATION OF FOREST SITES

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Phytogeographers have long recognized certain variations in the native vegetation of given regions, while phytoecologists have only recently made notable advances in the correlation of the vegetation with the climatic and edaphic factors of the habitat. Within the last decade the physiological ecologist has been doing some excellent work on the correlation of the native vegetation with the crop-producing potentialities of the land, the results of which have a very practical application in present-day agriculture.

As a result of detailed studies in the Great Plains region of eastern Colorado, Shantz[1] concludes that the character of the native plant cover can be used as a reliable indicator of the conditions favorable or unfavorable for crop production, provided the relation between the vegetation and the environment is correctly interpreted. The correlations which exist in the Great Plains between the different types of vegetation and the physical characteristics of the corresponding types of land are described in detail. Shantz discusses at length the ways in which the native vegetation may be used in that region to determine the adaptability of the land for dry farming. The crop production on wire-grass land during favorable years is almost as good as on short-grass land and during normal and dry years much better crops are produced on wire-grass than on short-grass land. Using the native vegetation as an indicator of the capabilities of crop production, the type of land that is characterized by the wire-grass association is classed as the most valuable agricultural land in eastern Colorado. That type of short-grass land which bears a considerable growth of wire-grass or *Psoralea* is classed with or very close to the wire-grass association land, since the presence of these plants indicate conditions intermediate between those of the typical wire-grass association and those indicated by the typical grama—buffalo-grass association. On new land where crops have not yet been produced, the character, growth, and condition of the native vegetation are the best possible indicators of crop production, either positive or negative, since plant growth is the ultimate criterion of the suitability of the physical environment.

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[1] Shantz, H. L. Native Vegetation as an Indicator of the Capabilities of Land for Crop Production in the Great Plains Area, U. S. Dept. of Agri., Bur. of Plant Ind. Bul. 201, 100 pp. 1911.

Kearney and others[2] have gone still farther in the scientific study of native vegetation from the indicator point of view in suggesting the possibility of correlating the distribution of the vegetation with the physical and chemical properties of the soil and the utilization of such a correlation in the classification of the agricultural potentialities of the land. The investigations in the Great Basin of central Utah were directed toward the solution of the problems of what types of vegetation indicate conditions of soil moisture favorable or unfavorable to dry farming and what types indicate the presence or absence of alkaline salts in sufficient quantities to injure cultivated crops. The results of the studies in Tooele Valley show that the different types of native vegetation indicate the conditions of soil moisture and alkalinity of the land on which they are found and consequently provide a basis for estimating its potentialities for crop production. A good stand and growth of sagebrush (*Artemisia tridentata*) indicates land that is well adapted to both dry and irrigation farming. Where the stand of sagebrush is open and the growth poor the good soil is usually too shallow for profitable crop production, at least without irrigation. Dry farming is precarious on land covered by the Kochia (*Kochia*

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[2] Kearney, T. H., Briggs, L. J., Shantz, H. L., McLane, J. W. and Piemeisel, R. L. Indicator Significance of Vegetation in Tooele Valley, Utah. Journal of Agricultural Research **1**: 365–417. 1914.

vestita) and shadscale (*Atriplex confertifolia*) associations, due to the shallowness of the alkali-free soil. Land occupied by the greasewood—shad-scale (*Sarcobatus vermiculatus* and *Atriplex confertifolia*) association is unsuitable for dry farming, but will produce good crops under irrigation.

The work on the correlation of the native vegetation with the crop-producing capabilities of the land has frequently suggested to the writer the possibility of utilizing the native vegetation in the determination of forest sites. In forestry, site is defined as an area considered as to its physical factors with reference to forest producing power; the combination of the climatic and edaphic conditions of an area or the forest habitat. For purposes of comparison the various sites are commonly segregated into site classes. Site class is a designation of the relative productive capacity or quality of different sites with reference to the species employed; the volume or the height produced at a given age being commonly used as the standard for classification. In the United States frequently only three classes are differentiated, designated by Roman numerals, quality I representing the most productive site class.

In a perusal of forestry literature one is impressed with the apparent fact that until only recently has much attention been given to the native vegetation, aside from the forest trees themselves, in the classification and segregation of forest sites. The majority of the references to the variation in the native herbaceous vegetation on different forest sites have been made incident to the describing of different sites or in characterizing their ground cover instead of from the indicator point of view.

The rather radical work of Cajander[3] must be cited as an exception to this statement. As a result of investigations of herbaceous and forest associations conducted in Finland, Germany, Austria-Hungary, Switzerland, Northern Russia and Siberia, Cajander concludes that, since no forester is in a position to determine definitely the limits of a dry or a moist soil, the difference in forest types must be based upon the character of the living ground cover as the clearest indicator of the site. Although Cajander admits that in virgin forests the composition of the forest itself correlated with the living ground cover is the best criterion of the physical conditions of growth, he further maintains that in forests which are under the influence of man the living ground cover alone may serve as a criterion and indicator of the physical conditions of the site. The latter statement is at variance with American ideas because of the failure to correlate the living ground cover with the different physical conditions of growth and the failure to appreciate the effect of the varying density of the forest cover on the living ground cover.

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[3] Cajander, A. K. Über Waldtypen, Helsingfors, 1909, Fennia 28, No. 2, 175 pp. Reviewed by Raphael Zon in Proc. Soc. Amer. Foresters **9**: 119–125. 1914.

In pointing out the value of the native vegetation as a criterion of the potential productivity of land and its application to modern land classification, Pearson[4] maintains that a forest may be regarded as the aggregate effect or the summation of the physical conditions obtaining on the site on which it grows and that the consideration of the potentiality of the land need not be confined to the trees. Shrubs, herbs and even the lower forms of plant life may be correlated effectively with the physical factors of the site and also with the tree growth. Pearson concludes that the simpler and more reliable basis for the determination of the adaptability of the site for different crops consists in the use of characteristic forms of the native vegetation as indicators of the physical conditions of the site.

Mason[5] reports the abundance of huckleberry (*Vaccinium scoparium*) on the poorer lodgepole pine (*Pinus contorta*) sites of the Rocky Mountains. Alder (*Alnus tenuifolia*) and willow frequently occur as underbrush in moist situations of the same forest type.

Clements[6] in discussing the vegetative succession on burned-over areas in the lodgepole pine forest of the central Rocky

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[4] Pearson, G. A. What is the Proper Basis for the Classification of Forest Land into Types? Proc. Soc. Amer. Foresters **8**: 79–84. 1913.

[5] Mason, D. T. The Life History of Lodgepole Pine in the Rocky Mountains. U. S. Dept. of Agri. Bul. 154, pp. 11–12. 1915.

[6] Clements, F. E. The Life History of Lodgepole Burn Forests, U. S. Dept. of Agri., Forest Service Bul. 79, 56 pp. 1910.

Mountains, points out differences in the density and composition of the living ground cover varying with the favorableness or unfavorableness of the different lodgepole pine sites. The vegetative succession occurring on the burns during the course of the reëstablishment of the original forest cover shows, in an interesting way, the superseding of the xerophytically-inclined vegetation by vegetation possessing more mesophytic tendencies, until, as the site becomes more and more mesophytic, the original forest cover is eventually established. The relative mesophytism of the site at each of the more or less distinct stages of the succession is indicated by the native vegetation occurring on the site at that particular time. It is true, however, that the vegetation of any of the unstable stages of the succession cannot be regarded as being indicative of the latent potentiality of the site. The ultimate climax stage of the succession must have been reached before much importance can be attached to the indicator significance of the native vegetation in the determination of site, especially from the standpoint of the forester.

Zon[7] in describing the forest types in which balsam fir (*Abies balsamea*) occurs, states that sphagnum and other mosses are the principal species which comprise the living ground cover of the swamp type. Fern moss replaces sphagnum as the predominating ground cover of the flat type. Ferns and certain flowering plants become the conspicuous herbaceous plants of the hardwood slope type in which balsam fir is reported as attaining its best individual development although the best stand development occurs in the flat type. The descriptions of the forest types are supported by lists which show the relative proportion of the different species and the character of the vegetation comprising the living ground cover of the swamp, flat, and hardwood slope types.

Hole and Singh[8] in studying the soil types and native vegetation of the sal forests in the vicinity of the Forest Research

[7] Zon, Raphael. Balsam Fir. U. S. Dept. of Agri. Bul. 55, pp. 4–7. 1914.

[8] Hole, R. S. and Singh, Puran. Oecology of Sal (*Shorea robusta*); Part I, Soil composition, soil-moisture, soil-aeration. Indian Forest Records, Vol. V, Part IV, pp. 13–14. 1914.

Institute, Dehra Dun, India, consider three principal soil types, each of which is characterized by distinct types of vegetation. The poorer soils, containing a large percentage of sand and a relatively small amount of silt, are frequently shallow, with gravel and boulders below. These soils are essentially dry and bear a dry forest with *Acacia catechu* and *Dalbergia sissoo* prominent, or grassland with *Saccharum munja* dominant. The well-aerated deep loams are covered with a sal forest or grassland with *Saccharum narenga* (often mixed with *Anthistiria gigantea* subsp. *arundinacea*) dominant. The poorly-aerated deep loams, differing from the well-aerated soils in containing more clay and silt, in actually being heavier, or in having the water-table nearer the surface, are characterized by a moist forest with *Betula frondosa, Stereospermum suaveolens, Terminalia, Cedrela toona* and others, or grassland with *Erianthus ravennae* (often mixed with *Anthistiria gigantea* subsp. *villosa*) dominant.

More recent work by the same investigators[9] indicates that the dominant grasses on an area are excellent indicators of the soil conditions. In northern India, where *Saccharum narenga* and *Anthistiria gigantea* subsp. *arundinacea* tend to be dominant, the soil moisture and aeration are suitable for the best development of sal and the moist type of sal forest prevails, in the shaded parts of which the reproduction suffers from poor soil aeration. Such grasses as *Saccharum munja, Saccharum spontaneum, Eragrostis cynosuroides, Imperata arundinacea, Vetiveria zizanioides, Andropogon contortus* and *Ischaemum angustifolium* usually indicate a soil too dry, or too heavy, for the best development of sal and such forests as occur are of the dry sal type.

Pearson[10], in discussing the effect of a cover of aspen (*Populus tremuloides*) upon the establishment of Douglas fir (*Pseudotsuga taxifolia*), has made a very interesting comparison of two different sites which occur at the transition between the Douglas fir and western yellow pine (*Pinus ponderosa*) types at an elevation of 8700 feet on the San Francisco Mountains in northern Arizona. Both sites had the same exposure but one was aspen-covered and the other was in the open. After making detailed studies of the physical factors of the two adjacent sites, the survival and development of Douglas fir planted on both sites and the correlation of the native vegetation occurring on the sites the conclusion was drawn that the open sites, due to their greater severity, should doubtless be reforested with western yellow pine (*Pinus ponderosa*) while the aspen-covered areas should be planted with Douglas fir. The aspen thickets supported a luxuriant growth of broad-leaved mesophytic herbaceous plants, such as *Frasera scabra*, *Pteridium aquilinum* and *Verbascum thapsus*, while grasses (*Muhlenbergia gracilis*, *Festuca arizonica*, *Festuca pseudovina*, and *Bromus polyanthus*) predominated in the openings. The growth of all herbaceous plants was invariably more luxuriant under the aspen than in the open.

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[9] Hole, R. S. and Singh, Puran. Oecology of Sal (*Shorea robusta*); Part II, Seedling Reproduction in Natural Forests and its Improvement. Indian Forest Records, Vol. V, Part IV, pp. 83–84. 1916.

[10] Pearson, G. A. The Rôle of Aspen in the Reforestation of Mountain Burns in Arizona and New Mexico. The Plant World **17**: 249–260. 1914.

Shreve[11] reports a rather marked variation in the distribution of the vegetation occurring in a forest of *Pinus arizonica* on the Santa Catalina Mountains in southern Arizona. Throughout the pine forest are to be found a large number of herbaceous perennials, the greater majority of which accompany the closed stands of pine. The occurrence of another large group of plants is confined to the near proximity of streams and stream-courses. In the dense shade of the evergreen-oak woodland *Pteris aquilina* is reported as being common, and it again becomes common in the pine forest above 7500 feet, but is infrequent in the lower portion of the forest region. *Alnus acuminata*, *Acer interius*, and *Quercus submollis* become frequent along streams at about 6800 feet. Herbaceous plants are reported as being found in increasing numbers at or near the banks of streams between 6000 and 7400 feet, among which may be mentioned *Juncus arizonicus*, *Aquilegia chrysantha*, *Thalictrum fendleri* var. *wrightii*, *Scrophularia* sp., *Trifolium pinetorum*, *Fragaria ovalis*, *Poten-*

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[11] Shreve, Forrest. The Vegetation of a Desert Mountain Range as Conditioned by Climatic Factors, Pub. 217, Carnegie Inst. Wash. 112 pp. 1915.

tilla thurberi, Hypericum formosum, Lobelia gruina, Agrimonia brittoniana var. *occidentalis, Gaura suffulta,* and *Tagetes lemmoni.*

Weaver[12] has recorded the variation in the vegetative undergrowth with a change of the site in the cedar (*Thuja plicata*) forest on the Thatuna Hills in southeastern Washington. Near the streams the forest floor is covered with *Athyrium cyclosorum* which gives way farther back to a rather dense growth of *Rubus parviflorus, Vagnera amplexicaulis, Tiarella unifoliata, Trillium ovatum, Clintonia uniflora, Disporum majus, Pyrola* sp., *Actaea spicata arguta,* and *Coptis occidentalis, Viola* sp., *Streptopus amplexifolius,* and *Phegopteris dryopteris.* These together with the cedar seedlings comprise the characteristic undergrowth, while farther up the slope there is almost no living ground cover.

Fuller[13] notes the relation between the mesophytism of a site and the undergrowth in some comparatively undisturbed beech-maple forests about 45 miles southeast of Chicago, when he states that the lower evaporation in the ravine may be a sufficient explanation for the presence upon its slopes of a much greater abundance of such delicate forms as *Dicentra canadensis, D. cucullaria, Impatiens biflora,* and *Asplenium angustifolium.*

Peters,[14] as a result of observations made in Northampton County, Pennsylvania as early as 1806, calls attention to the fact that the timber alone is not always an invariable indicator of the capabilities of the land. Hemlock (*Tsuga canadensis*), white pine (*Pinus strobus*), and pitch pine (*Pinus rigida*) were reported as occurring on deep, fertile loams as well as on the thinnest, sterile, sandy soils. It is readily seen that the vegetation must be properly correlated with its habitat and the relation between vegetation and environment must be correctly interpreted.

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[12] Weaver, John E. Evaporation and Plant Succession in Southeastern Washington and Adjacent Idaho. The Plant World **17**: 273-294. 1914.

[13] Fuller, George D. Evaporation and the Stratification of Vegetation. Bot. Gaz. **54**: 424–426. 1912.

[14] Peters, Richard. The Departure of Southern Pine Timber and Proof of the Tendency in Nature to a Change in Products on the Same Soil. Memoirs of the Philadelphia Society for Promoting Agriculture, containing communications on various subjects in husbandry, and rural affairs, Vol. I, page 30, Philadelphia. 1815. From notes on plant succession abstracted and furnished by Dr. H. L. Shantz.

It should be clearly recognized that the use of native vegetation as an indicator of forest sites is not without certain limitations. The use of native shrubby, and particularly herbaceous, vegetation as forest site indicators is not exactly comparable to using native open-land vegetation as an indicator of the crop productivity of an open-land site. In the case of the forest site the presence or absence of an over-wood must be recognized as an influential factor. The use of shrubby and herbaceous vegetation as indicators of forest sites encounters more obstacles in the dense Douglas fir, lodgepole pine, and Engelmann spruce (*Picea engelmanni*) forests than in the comparatively open western yellow pine forests. In the dense forests herbaceous plants are rather scarce except in partial openings or where the stand is below its normal density. The vegetation of the denser forests also varies in its composition from place to place, not only according to the favorableness of the site, but also with the density of the crown cover and consequently the amount of shade in the forest. The floor of the fir, spruce and lodgepole pine forests is more heavily and continuously shaded than that of the densest stands of western yellow pine. The factor of shade is of great importance in conditioning the character of the shrubby and herbaceous vegetation of dense forests.

While engaged in the remeasurement of a set of permanent sample plots aggregating 26.4 acres on the San Mateo Division of the Datil National Forest in west central New Mexico in the summer of 1915 the writer was impressed with the variation in the vegetation occurring on the different western yellow pine sites. The San Mateo Mountain range extends in a general north and south direction and rises to a height of 9500 to 10,500 feet above sea level. The north and west portions of the mountains slope quite gradually to the adjacent rolling plains. The east and south portions of the range break off quite abruptly to the plains. The majority of the steeper east and south aspects bear such species as *Juniperus monosperma*, *J. pachyphloea*, *Pinus edulis*, *Quercus chry-*

solepis, *Q. undulata*, and *Cercocarpus breviflorus*, while western yellow pine predominates on the more gradual slopes which are more retentive of soil moisture. In the more protected and more moist situations, such as cañon bottoms and north slopes at the higher elevations, *Pseudotsuga taxifolia*, *Abies concolor*, *Pinus flexilis*, *Picea engelmanni*, *P. parryana*, and *Populus tremuloides* are found. Western yellow pine occupies the more gradual slopes and situations at the intermediate elevations. A rather erratic altitudinal distribution of the species is evident in the San Mateo Mountains. At the elevation of the plots, which is approximately 8000 feet above sea level the cañon bottoms, north slopes and lower south slopes are occupied by an almost pure stand of western yellow pine which is typical of the San Mateo Mountains, while a belt of the more xerophytic species is frequently found on the more exposed upper south slopes above the western yellow pine.

The plots were established in 1910 with the principal object of determining the rate of growth and decadence of western yellow pine in this locality. They are located in the cañon bottoms and on the slopes, the gradients of which vary from 3 to 50%. Prior to the establishment of the plots the area had been cut-over, removing many of the mature and over-mature trees and a large proportion of the merchantable material. A modified selection system of cutting to a variable diameter limit was followed when the timber was marked. Occasionally large merchantable trees were reserved as seed or fire insurance trees or to maintain the general continuity of the forest cover. When the plots were established in 1910, the diameters and total heights of all trees 3.6 inches or more in diameter at 4.5 feet above the ground were measured. Each tree was described, especially with reference to its vigor, health or decadence, its crown class and all diseases, defects or abnormalities were noted. The plots were remeasured and examined in 1915, thus giving their history for the intervening five-year period.

Two well-recognized forms of *Pinus ponderosa* are distinguished, "black jack" and "yellow pine," based on age, rate of growth, and the resulting color of the bark. The term "black jack" applies to the young, vigorous trees under 125 to 150 years old which are characterized by a dark, almost black, or dark brown, narrow-furrowed bark. The "yellow pine" form comprises the older trees which are characterized by a yellowish or reddish brown, widely furrowed bark. A marked difference occurs between the form and volume of "black jacks" and "yellow pines." The average "black jack" has a greater taper, a more rapid rate of growth and approximately 10% smaller cubic volume than the average "yellow pine" of the same diameter and height, which are the main reasons for the segregation of "black jack" and "yellow pine" by technical foresters.

Two distinct western yellow pine sites were very readily recognized through apparent differences in the composition, density, rate of growth, and vigor of the forest and the corresponding differences in the shrubby and herbaceous vegetation. The soil of Site I, which occupies the cañon bottoms and the protected north slopes, is a deep gravelly clay loam containing considerable amounts of organic matter and is consequently comparatively retentive of soil moisture. Site II, which as a shallow well-drained gravelly soil containing little organic matter, is found on the ridge-tops and exposed south slopes. At the time of the 1915 examination the two sites were segregated and each was mapped separately. Approximately 16.0 acres were classed as Site I, while 10.4 acres fell into Site II.

The growth data were segregated in separate compilations for each site and for the two forms of western yellow pine.[15] The total volume growth or increment of all trees measured was computed for the five-year period. The total volumes were computed by applying a volume table based on diameter and total height to the dimensions of each tree at each time of measurement. The difference between the total volumes at each time of measurement represents the periodic increment and the average volume growth per year during the period considered is the periodic annual increment. Table 1 shows the increment of both forms of western yellow pine for Sites I and II. The data are significant in that they indicate the relative productivity of the two sites and the variability of the increment depending on the kind and amount of growing stock. The data given in table 1 represent the net increment since the volumes of all trees which died during the quinquennium were considered as negative increment and the volumes of all trees growing into the 4-inch class as positive increment. The fact that the plots were cut-over in 1910 under Forest Service regulations accounts for the relatively small amount of merchantable growing stock. The abundance of poles from 4 to 10 inches in diameter breast high which were left on the area accounts for the proportionately greater cubic volume of the growing stock. Since a number of trees grew into the merchantable class during

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[15] The writer is indebted to Forest Examiners H. B. Wales and J. W. Stokes for assistance rendered in the collection and compilation of the growth data presented in this paper.

TABLE 1

Increment data for 26.4 acres of typical western yellow pine in the San Mateo Mountains of west central New Mexico, based on five years' growth

	TOTAL MERCHANTABLE VOLUME*		MERCHANTABLE INCREMENT, 1910–1915			TOTAL CUBIC VOLUME†		CUBIC INCREMENT, 1910–1915		
	1910	1915	Periodic	Periodic annual	Annual, per acre	1910	1915	Periodic	Periodic annual	Annual, per acre
	feet B. M.	*feet B. M.*	*feet B. M.*	*feet B. M.*	*feet B. M.*	*cu. ft.*	*cu. ft.*	*cu. ft.*	*cu. ft.*	*cu. ft.*
Site I										
"Black Jack"....	16,720	22,700	5,980	1,196	75	9,723.4	10,872.3	1,148.9	229.8	14.4
"Yellow Pine"..	22,250	26,690	4,440	888	55	4,872.5	5,730.7	858.2	171.6	10.7
Total for species...	38,970	49,390	10,420	2,084	130	14,595.9	16,603.0	2,007.1	401.4	25.1
Site II										
"Black Jack"....	3,110	3,720	610	122	12	2,955.5	3,147.1	191.6	38.3	3.7
"Yellow Pine"...	8,040	10,450	2,410	482	46	2,642.6	3,244.7	602.1	120.4	11.6
Total for species...	11,150	14,170	3,020	604	58	5,598.1	6,391.8	793.7	158.7	15.3

* Includes the volumes in feet, board measure, of all western yellow pine trees 12 inches and over in diameter breast high.

† Includes the volumes in cubic feet of all western yellow pine trees 3.6 inches and over in diameter breast high.

the quinquennium and are included for the first time in the 1915 board-measure computations, the annual increment per acre as shown in board feet is perhaps somewhat greater than the mean annual increment would be for a longer period. The annual increment per acre in cubic feet is therefore considered as a better criterion of the relative productivity of each site. It is noteworthy that Site I produced 25.1 cubic feet per acre per year as against 15.3 cubic feet for Site II or, in other words Site I produced a cubic volume of 64% more than Site II during the same five-year period.

It is also interesting to compare the average breast high diameter growth of both forms of western yellow pine on the two sites. "Black jack" averaged 0.85 inch on Site I while the diameter growth of this form on Site II was only 0.71 inch. The breast high diameter growth of "yellow pine" on Site I averaged 0.75 inch, while on Site II it averaged only 0.54 inch. The mean diameter growth for the species as a whole amounted to 0.83 inch on Site I and 0.68 inch on Site II.

During the course of the compilation of the pertinent data presented above an opportunity was offered to compare the average increment per tree of the different crown classes. All of the trees on the permanent sample plots were classified according to their dominance or relative position in the crown cover, into the following crown classes:

X = *Isolated:* Trees growing in the open which do not form a contiguous part of the regular forest canopy.

D = *Dominant:* Trees with crowns extending above the general level of the forest canopy and receiving full light from above and partly from the side; larger than the average trees in the stand, and with crowns well-developed but possibly somewhat crowded.

C = *Codominant:* Trees with crowns forming the general level of the forest canopy and receiving full light from above but comparatively little from the sides; usually with medium-sized crowns more or less crowded on the sides.

I = *Intermediate:* Trees with crowns below, but still extending into the general level of the forest canopy, receiving a little direct light from above but none from the sides, usually with small crowns considerably crowded on the sides.

S = *Suppressed:* Trees with crowns below the general level of the forest canopy and receiving no direct light either from above or from the sides; usually with small, poorly developed crowns.

Table 2 shows the average increment per tree for the different crown classes on Sites I and II, only those trees being included which were living and were measured in 1910 and 1915. The greater apparent increment of the dominant crown class might be explained by the fact that in the X class a greater amount of limb-wood is produced, while in the dominant class, due to their relative position in the forest, there is a stimulation in the production of body-wood which is the portion of the tree measured to determine the increment. When the individual trees, the component parts of an aggregate stand, are given separate consideration it is evident that not only the effects of the physical site are revealed in the increment but also the effects of the individual's associates, especially their influence on the amount of light the individual receives or the amount of growing space available for its use. Although the average increment per tree varies directly with the favorableness of the conditions of the site, the writer does not wish to leave the impression that crown form may be regarded as an expression of site quality.

TABLE 2

Periodic cubic increment of western yellow pine segregated by crown classes for Sites I and II

CROWN CLASS	SITE I			SITE II			COMPARATIVE INCREMENT OF SITE II WITH SITE I
	Basis	Total periodic increment	Periodic increment per tree	Basis	Total periodic increment	Periodic increment per tree	
	no. of trees	*cu. ft.*	*cu. ft.*	*no. of trees*	*cu. ft.*	*cu. ft.*	*per cent*
X	230	622.3	2.70	204	314.1	1.54	57
D	168	617.8	3.68	87	184.4	2.12	57
C	411	721.4	1.75	247	268.9	1.08	61
I	119	69.9	.58	74	29.5	.39	67
S	14	4.4	.31	5	1.2	.24	77

It is true that crown form reflects the growing conditions as determined by competition but competition cannot be regarded as a site factor.

The differences in the native vegetation on the two different sites were so apparent that the writer immediately conceived the idea that it could be correlated with increment and used as an additional criterion in the determination of the productivity of a given forest site.

The vegetation on a number of 5 by 10-foot quadrats was listed in addition to that on the regular permanent reproduction plots of the same size, which were instituted with the primary object of studying the establishment of natural reproduction on the cut-over areas. Although the plots had been cut-over in 1910, the logging operation which was conducted under Forest Service regulations did not destroy the continuity of the forest canopy sufficiently to noticeably interfere with the stabilized climax vegetation since the virgin western yellow pine forest was originally comparatively open and park-like. The vegetation which was found on these list quadrats is systematically summarized in table 3, showing for the cañon bottoms, the north slopes, south slopes and ridge tops the percentage of the quadrats on which each species was found. The arrangement of the families is essentially an adaptation of Engler and Prantl's "Die Natürlichen Pflanzenfamilien" as used in the United States National Herbarium, which aims to indicate something of the natural developmental relationships of the families by proceeding from the simpler to the more complex. The writer desires to express his indebtedness to Prof. J. J. Thornber of the University of Arizona and Grazing Examiner R. R. Hill of the United States Forest Service for determining numerous plants and for verifying the list. A perusal of the list shows marked differences in the individuality of the vegetation of the two sites. Site I is shown to produce such typical mesophytes as *Mnium* sp., *Agrostis hiemalis, Bromus polyanthus, Muhlenbergia wrightii, Populus tremuloides, Arenaria confusa, Cerastium longipedunculatum, Silene laciniata, Aquilegia chrysantha, Thalictrum wrightii, Draba helleriana, Potentilla atrorubens, P. crinita, Rosa fendleri,*

TABLE 3

Systematic summary of vegetation on fifty-three list quadrats taken at random on the San Mateo Division of the Datil National Forest, New Mexico

	PER CENT OF QUADRATS ON WHICH SPECIES OCCUR					
	Cañon bottom (12 quadrats)	North slope (13 quadrats)	Total site I (25 quadrats)	South slope (23 quadrats)	Ridge top (5 quadrats)	Total site II (28 quadrats)
BRYACEAE						
Mnium sp.	8	15	12	0	0	0
POACEAE						
Agropyron tenerum Vasey	8	0	4	0	0	0
Agrostis hiemalis (Walt.) B. S. P.	25	0	12	0	0	0
Blepharoneuron tricholepis (Torr.) Nash	17	0	8	56	20	50
Bromus polyanthus Shear	8	0	4	0	0	0
Bromus porteri (Coult.) Nash	50	69	60	30	0	25
Festuca arizonica Vasey	17	15	16	0	20	4
Koeleria cristata (L.) Pers.	42	69	56	74	100	64
Muhlenbergia gracilis (H. B. K.) Trin.	33	54	44	65	40	61
Muhlenbergia wrightii Vasey	8	0	4	0	0	0
Poa rupicola Nash	0	0	0	39	0	32
Sitanion brevifolium J. G. Smith	17	31	24	17	80	29
Sporobolus ramulosus (H. B. K.) Kunth	17	15	16	13	0	11
CYPERACEAE						
Cyperus fendlerianus Boeckel	17	23	20	61	20	54
COMMELINACEAE						
Commelina dianthifolia Delile	0	0	0	0	20	4
LILIACEAE						
Yucca sp.	0	0	0	4	0	4
ORCHIDACEAE						
Achroanthes montana (Rothr.) Greene	0	0	0	0	20	4
SALICACEAE						
Populus tremuloides Michx.	8	8	8	0	0	0
FAGACEAE						
Quercus gambelii Nutt.	0	46	24	9	20	11
Quercus grisea Liebm.	0	0	0	9	40	14
POLYGONACEAE						
Eriogonum alatum Torr.	0	8	4	22	40	25
Eriogonum jamesii Benth.	0	8	4	0	20	4
Polygonum douglasii Greene	0	0	0	4	0	4
CHENOPODIACEAE						
Chenopodium ob*longifolium* (S. Wats.) Rydb.	0	8	4	0	0	0

TABLE 3—Continued

	PER CENT OF QUADRATS ON WHICH SPECIES OCCUR					
	Cañon bottom (12 quadrats)	North slope (13 quadrats)	Total site I (25 quadrats)	South slope (23 quadrats)	Ridge top (5 quadrats)	Total site II (28 quadrats)
NYCTAGINACEAE						
Allionia divaricata Rydb.	0	0	0	4	0	4
PORTULACACEAE						
Portulaca oleracea L.	0	0	0	13	0	11
SILENACEAE.						
Arenaria confusa Rydb.	17	31	24	0	0	0
Cerastium longipedunculatum Muhl.	8	0	4	0	0	0
Silene laciniata Cav.	0	23	12	0	0	0
Silene pringlei S. Wats.	0	8	4	9	20	11
RANUNCULACEAE						
Aquilegia chrysantha A. Gray	8	0	4	0	0	0
Thalictrum wrightii A. Gray	0	31	16	0	0	0
BRASSICACEAE						
Draba helleriana Greene	0	8	4	0	0	0
Erysimum elatum Nutt.	8	0	4	4	0	4
Heterothrix longifolia (Benth.) Rydb.	0	0	0	17	0	14
ROSACEAE						
Cercocarpus breviflorus A. Gray	0	0	0	9	0	7
Fragaria bracteata Heller	8	31	20	4	0	4
Potentilla atrorubens Rydb.	8	0	4	0	0	0
Potentilla crinita A. Gray	8	0	4	0	0	0
Rosa fendleri Crép.	33	38	36	0	0	0
FABACEAE						
Anisolotus wrightii (A. Gray) Rydb.	8	8	8	26	60	32
Aragallus lambertii Greene	8	23	16	0	20	4
Astragalus accumbens Sheld.	8	38	24	30	80	39
Lathyrus graminifolius (S. Wats.) White	17	62	40	35	60	39
Phaseolus angustissimus A. Gray	0	8	4	0	0	0
Vicia americana Muhl.	17	38	28	26	0	21
OXALIDACEAE						
Oxalis stricta L.	0	8	4	0	0	0
GERANIACEAE						
Geranium fremontii Torr.	25	8	16	4	0	4
Geranium richardsonii Fisch. & Trautv.	0	8	4	0	0	0
LINACEAE						
Linum neomexicanum Greene	0	8	4	0	0	0
EUPHORBIACEAE						
Euphorbia fendleri Torr. & Gray	0	8	4	0	0	0

TABLE 3—Continued

	PER CENT OF QUADRATS ON WHICH SPECIES OCCUR					
	Cañon bottom (12 quadrats)	North slope (13 quadrats)	Total site I (25 quadrats)	South slope (23 quadrats)	Ridge top (5 quadrats)	Total site II (28 quadrats)
RHAMNACEAE						
Ceanothus fendleri A. Gray	17	0	8	9	40	14
Viola neomexicana Greene	0	23	16	0	0	0
APIACEAE						
Pseudocymopterus tenuifolius (A. Gray) Rydb.	0	38	20	48	60	50
GENTIANACEAE						
Amarella scopulorum Greene	0	15	8	0	0	0
Gentiana bigelovii A. Gray	8	8	8	0	0	0
POLEMONICACEAE						
Gilia greeneana Woot. & Standl.	0	0	0	22	0	18
BORAGINACEAE						
Lithospermum multiflorum Torr.	8	23	16	4	20	7
MENTHACEAE						
Prunella vulgaris L.	8	0	4	0	0	0
SCROPHULARIACEAE						
Castilleja trinervis Rydb.	16	54	36	0	20	4
Mimulus langsdorfii Don	8	0	4	0	0	0
Pentstemon gracilis Nutt.	0	15	8	26	40	29
Pentstemon virgatus A. Gray	8	8	8	0	0	0
CAMPANULACEAE						
Campanula petiolata A. DC.	8	8	8	0	0	0
ASTERACEAE						
Achillea lanulosa Nutt.	33	69	52	4	0	4
Artemesia forwoodii S. Wats.	8	0	4	30	0	25
Artemesia mexicana Willd.	17	46	32	0	0	0
Artemesia sp.	0	8	4	4	40	11
Chrysopsis villosa (Pursh) Hook.	8	15	12	44	20	43
Coleosanthus petiolaris (A. Gray) Greene	0	0	0	4	0	4
Conyza coulteri A. Gray	0	0	0	4	0	4
Dugaldea hoopesii (A. Gray) Rydb.	25	15	20	56	100	64
Erigeron divergens Torr. & Gray	8	0	4	0	0	0
Gymnolomia multiflora (Nutt.) Benth & Hook.	17	0	8	4	20	7
Hymenopappus mexicanus A. Gray	0	8	4	17	20	18
Hymenopappus radiatus Rose	0	0	0	13	0	11
Machaeranthera aquifolia Greene	42	77	60	35	20	32
Oreochrysum parryi (A. Gray) Rydb?	0	0	0	17	20	18
Senecio quaerens Greene?	0	0	0	13	20	14
Solidago neomexicana (A. Gray) Woot. & Stand.	0	38	20	0	0	0
Stevia serrata Cav.	17	0	8	0	0	0
Villanova dissecta (A. Gray) Rydb.	25	0	12	9	0	7

Geranium richardsonii, Viola neomexicana, Amarella scopulorum, Gentiana bigelowii, Prunella vulgaris, Mimulus langsdorfii, Penstemon virgatus, Campanula petiolata, and *Solidago neomexicana*. Site II bears such transitory species and xerophytes as *Poa rupicola, Commelina dianthifolia, Yucca* sp., *Quercus grisea, Portulaca oleracea, Heterothrix longifolia, Cercocarpus breviflorus*, and *Hymenopappus radiatus*. The moss (*Mnium* sp.) was only found in cool, moist and shaded situations, thereby indicating unusually favorable site conditions. The monkey flower (*Mimulus langsdorfii*) was the only plant which was confined to the proximity of water, indicating excessive soil moisture conditions.

Practically all of the species listed as occurring entirely on Site II, which do not overlap on other sites, were found in hot, dry and unshaded situations and might be regarded tentatively as indicators of poor western yellow pine sites in the San Mateo Mountains. The mesophytes listed as possible Site I indicators were not found on poorer sites in this locality. However, it may be true that further detailed studies in the San Mateo Mountains might require a different listing of the vegetation than that here given. A number of the species listed as occurring on only one site are, to the writer's personal knowledge, known to occur on different sites in other parts of the Southwest. The vegetation on Site II was comparatively sparse and more open than on Site I where it was also more luxuriant and vigorous. Those species which were found to overlap on both sites normally made their optimum development on Site I. Approximately twice as many species were found on Site I as on Site II. It is therefore with some reluctance that certain opinions are advanced regarding the indicator significance of the natural vegetation. The writer is not attempting, however, to state that certain species are positive site indicators or that others are negative indicators. The rather superficial nature of the field observations will only permit of a few more or less general statements concerning the latent possibilities in the use of the native vegetation in the classification of forest sites and in the determination of their productivity.

In studying the indicator significance of the native vegetation it is necessary to go directly to the individual species instead of attempting to stop at the association, society, or community, since the vegetation as an integral is composed of individual species and in intergrating the vegetation it must be remembered that the behavior of the vegetation is a resultant function of the behavior of the component species. It is impossible in arid and semi-arid regions having many diverse biological growth forms, to select a group of plants which may be regarded as associates without finding that the association may have been disorganized elsewhere and that some of the individuals enter into other associations as component parts.

It is freely admitted that the best ultimate criterion of site quality is the increment of the aborescent species concerned, as judged by the measurement of an approximately fully stocked stand. In cases where the increment data are rather meager or are entirely lacking the native vegetation present should serve as a valuable criterion of site for those species addicted to growing in rather open, park-like stands, such as western yellow pine. In this connection it should be remembered that a plant rarely requires more than a few years at most to reach the adult form, while the forest often requires a century or even two in which to reach maturity. The writer believes that the native vegetation found on deforested areas may be considered as a criterion of the latent potentialities of the site for forest production provided the vegetation has not been too severely and too recently disturbed and that the more important phases of the successional series are properly understood.

Studies are under way at the Utah Forest Experiment Station in central Utah, the object of which is to determine the feasibility of using native plants as indicators of suitable forest planting sites. By making detailed studies of the root systems and subterranean moisture-absorbing surfaces of the typical herbaceous, shrubby and arborescent species of each important association, the value of the native vegetation as indicators of those climatic and edaphic conditions under which the important coniferous species may be planted successfully should be determined. The studies of the depth and character of the root systems will lead to the determination of the different successional stages of the native vegetation on burned-over or cut-over land. It is very probable that the sudden removal of the vegetative cover renders the site less favorable for the successful establishment and optimum development of the climax species and the more favorable for the invasion of species normally occurring on poorer sites at lower elevations.

The fundamental study of forest planting sites logically resolves itself into three categories: (1) the empirical establishment of plantations and the observation and study of their survival and subsequent development, (2) the measurement and study of the most important physical factors of the site, such as the available soil moisture or growth water and evaporation, and (3) the indicator significance of the native vegetation occurring on the sites implying a very careful correlation of all three phases, especially the correlation of the species with the physical conditions which produce them, and a study of the relative transpiration of the natural and planted vegetation.

It is readily conceivable that site studies of this character will be of the utmost value in explaining the presence or absence of tree growth on certain areas, in the judicious selection of the proper species and sites in the reforestation of much of the denuded forest land of the United States, and in establishing a working basis for the classification of the potential productivity of forest lands. Only after considering the relative agricultural and forest productivity of the land on a combined scientific and economic basis, can a positive conclusion be reached that its greatest utility lies in its use for forestry or for agricultural purposes.

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